Chemical Engineering Progress

All engineers concerned in development will find some valuable suggestions in Opinion & Comment which is written this month by Bill Nichols, director of the general engineering department of the Monsanto Chemical Co. Data for design of plants are an engineering must, as we all know, and Bill pounds the table a bit, wondering about the way engineers get the facts they need, and suggesting a pre-pilot plant, pilot plant.

Big openings for graduates—Are you interested in metallurgy, in research and development? Do you have a knowledge of chemical equipment? Possibly you have had experience in industrial and chemical plant design. See the Classified Section this month.

This month's issue contains a post-meeting review (Minneapolis) and a pre-meeting story (Columbus). It's too late to nurse regrets over not attending the regional meeting but time aplenty to arrange your affairs so that you can meet your friends at the Buckeye state meeting Dec. 3.

Are chemical engineers bad supervisors? Does their management I.Q. need polishing? As a group they failed to get a passing mark on the management test given at Minneapolis. See page 16.

Waldemar Kaempffert, writing in a recent issue of the New York Times says that an engineer would have done a better job in designing the human body. An engineer, he claims, "would not have put the whole weight of the body on the small of the curved back and on two inadequate feet, nor would he have made the heart strain itself by pumping blood vertically against gravity." Thinking about W. K.'s fault-finding, we admit he has something, but for a perfect body engineering-wise, the only thing we can visualize is a snake.

Another reminder to C.E.P.—C.A.R.E. (in cooperation with U.N.E.S.C.O.) is continuing to accept money for the purchase of scientific and professional books for public and university libraries and technical groups in more than a dozen countries. Read on page 20 how technical knowledge can be made available to Louvain University.

Chemical Engineering Progress

Volume 46

Number 10

OCTOBER 1950

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OPINION AND COMMENT

WHAT! NO CRYSTAL BALL?

A COMMON complaint among chemical engineers doing process engineering is that they never have enough fundamental information to do a good design job. The justice of this complaint is hardly to be questioned, although there may be valid reasons for going ahead with design in the absence of "enough information."

The laboratory research phase of a complete project is likely to represent a relatively small portion of the total project cost. As a matter of fact, it is not uncommon to find that overdesign, or rectification of defects in design, may amount to more than the whole cost of the laboratory phase. Why is it, then, that there appears to be so much difficulty in securing for engineering design the data which the engineers consider advisable, if not essential?

One of the problems is to determine when to secure detailed data, lacking definite indications that the project ever will reach engineering phases. Thoughtful research direction may identify crucial items on which excessive attention may be risked. Perhaps in the long run such skillful treatment would pay off. By the time engineering information is necessary, the research team may be broken up, the personnel probably have gone on to other work and samples may be exhausted or lost. In such an event, then, engineers may be asking the research people to plow over old ground, a procedure seldom entertained with pleasure by the typical researcher. Requests for more data may encounter active or passive resistance and perhaps at most, dignified acquiescence rather than enthusiastic cooperation. In the long, complicated, expensive course of the development of a project, engineering need for data usually appears a long time after the corresponding laboratory work has been completed and the equipment has been dismantled, but some resistance to determining physical properties is based on the fact that such work is just plain uninteresting. It seems to escape most people that empirical experiments, though more interesting, are much more costly than securing fundamental data where the latter course will suffice.

Pilot plant operations of the usual sort are extremely expensive, both as regards equipment and operating costs. It is doubtful whether there is ever occasion for deciding to operate a pilot plant on a substantial scale unless there is already ample evidence of the economic soundness of the project. The ordinary pilot plant is not the place to study the fundamental characteristics of a chemical process, though it is a rather common misconception that no other studies are dependable. At worst, a pilot plant represents lack of proper confidence in small-scale work. At best, a pilot plant can be a demonstration unit. Ideally, it should function perfectly, just as one hopes a full-scale plant will do. If a pilot unit does not function in accordance with expectations, then it is evident that research or design work has been less than fully effective.

We are prone to rush into pilot scale work long before we should. Some of this inordinate haste is associated with the tendency for the talented industrial research people to press ever onward and to be bored with details involved in the study of reaction conditions, corrosion phenomena, sampling and analysis, physical properties of reactants, intermediates and products. Some of this haste is due to management pressures, once real promise of valuable results has been indicated.
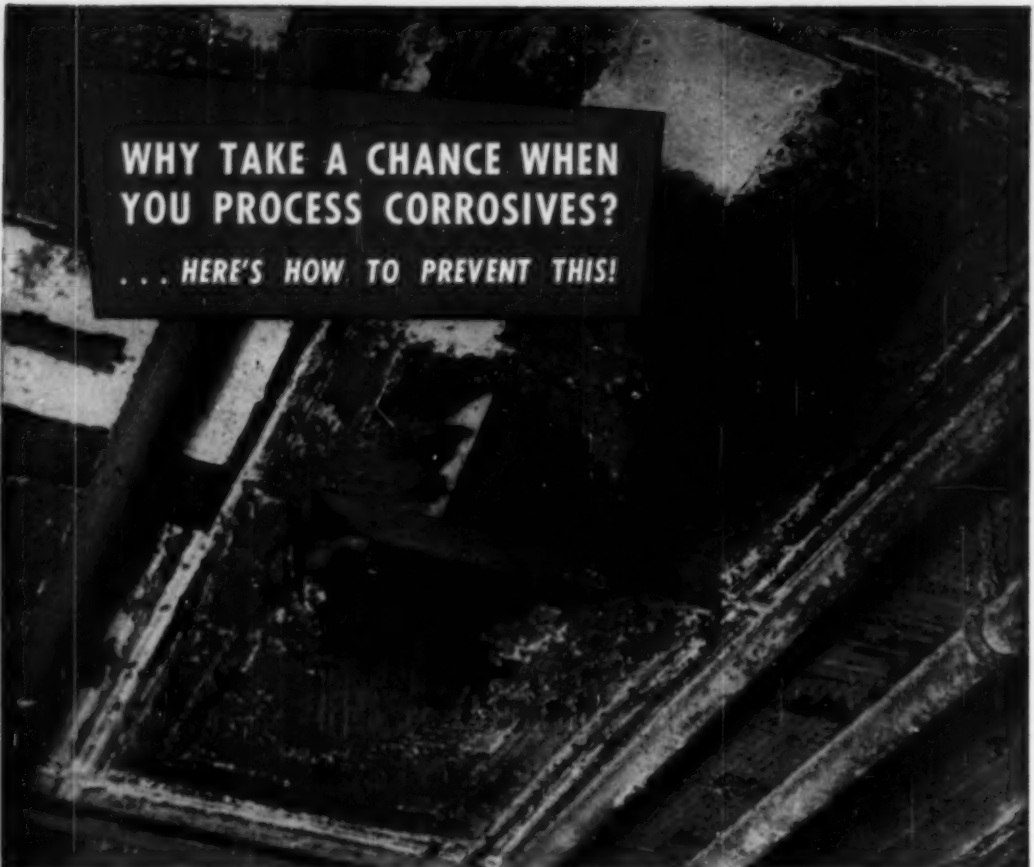
One way to help the situation is to cultivate the principle that design engineering should be done with, rather than without, pertinent fundamental data. At the earliest time feasible, design engineers should outline items of information needed and procuring this information should be regarded as a normal part of the laboratory research job. Reassembling equipment and reassigning personnel need not be exasperating or repugnant to research management if there is common understanding of the importance of the work. Devotion of the inconsiderable funds for this sort of activity ought to pay large dividends in engineering progress and quality of plants.

There is a further thought which deserves consideration. We have a profusion of devices at our command, nowadays, which make it possible to create laboratory apparatus assemblies and measure temperatures, pressures, concentrations, flows, and so forth, in ways not dreamed of a few years ago. Is it not possible that we often overlook opportunities to solve problems at the laboratory level in our fear of abnormally high material or radiation losses? Are we not still too often substituting empirical experimenting for fundamental studies?

It is suggested that in some cases at least a pilot plant may be entirely feasible on a miniature scale. Such units have been used with great success. Engineers are prone to think too rigidly in terms of large-scale operations, and research people too apt to reserve for themselves all small-scale work. Whether it supersedes the true pilot plant or not, perhaps there are possibilities in "miniature pilot plants," which is to say, integrated units on the laboratory scale, *designed by engineers*. In such units, the data the engineers say they need may be secured, in accordance with a prepared plan, and including materials of construction studies. Admittedly, great ingenuity may be demanded to solve problems imposed by the small size of plant elements and the small quantities of materials flowing but this sort of ingenuity is one of the principal assets of creative chemists, engineers and physicists. Along with "miniature plant" operations might go the determinations of physical properties and system characteristics that would complete the fund of information which the design engineers would find of greatest value.

Certainly there seems ample opportunity to save money by such means and it is questionable whether over-all time requirements would be any greater than if such a step were omitted. Perhaps we ought really to "make our mistakes on a small scale" instead of just enunciating the principle.

W. T. Nichols

In the September issue Chemical Engineering Progress published three papers contributed to the Chlorine-Alkali Symposium at the Houston meeting. . . . In this issue the symposium is concluded with the publication of two more papers . . . the first covers the chlorination of organic materials during the Deacon reaction and the second describes the experimental work done on the Dowtherm-heated commercial evaporator.

ORGANIC CHLORINATION
WITH HCl AND AIR

ROBERT M. CRAWFORD

Consulting Chemical Engineer, Buffalo, New York

THE Deacon process for making chlorine consists in passing a mixture of hydrogen chloride and air over a catalyst consisting of a porous carrier, such as burnt clay, pumice, and the like, which has been impregnated with a solution of a copper salt, usually the chloride. At temperatures of 400° C. to 500° C. the hydrogen chloride is, in part, converted to chlorine. This reaction is a reversible one and reaches an equilibrium, with respect to temperature, as will be shown later. It is recorded that at a temperature of 450° C. and with 100% excess oxygen, as O_2, the exit products have a composition of about 25% HCl and 75% Cl_2.

When chlorine gas is used for the chlorination of organic compounds, such as benzene, toluene, methane and the like, one half is converted to hydrogen chloride, which is usually recovered as a salable by-product of such reactions.

Since, in the Deacon reaction, hydrogen chlorine is converted to chlorine, and, in organic chlorinations with chlorine gas, chlorine is converted to hydrogen chloride, it would appear reasonable to effect chlorination of an organic compound by supplying the vapor of the organic substance to the reactants of the Deacon process and expect the chlorine liberated to chlorinate the organic substance. Under such conditions the generic reaction would be:

$$RH + HCl + \tfrac{1}{2}O_2 = RCl + H_2O \quad \text{·}(1)$$
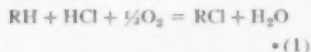
Theoretically the removal of chlorine, as formed, by chlorination of the organic would tend to drive the reaction to completion, to the right, and contribute to greater chlorine liberation.

In the early 1920's Ernst and Wahl, of I. G. Farben, reported the chlorination of methane (7), ethane (8), and benzene (9) by passing a mixture of the respective organic vapor, hydrogen chloride and air over a supported cata-

lyst (cupric chloride on pumice), at temperatures above 300° C. The patents yield little, or no, information with respect to yields or methods of application. At about the same time Tizard (17) patented a two-step process for chlorinating hydrocarbons by contact with a metal halide, $CuCl_2$, at about 500° C. He used a supported catalyst and an intermittent process wherein the reduced salt is regenerated by separate treatment with hydrogen chloride and oxygen. The following reactions probably take place:

chlorination

$$RH + 2CuCl_2 = RCl + Cu_2Cl_2 + HCl \quad (2)$$

regeneration

$$Cu_2Cl_2 + \tfrac{1}{2}O_2 + 2HCl = 2CuCl_2 + H_2O \quad (3)$$
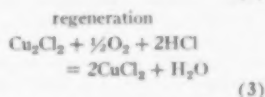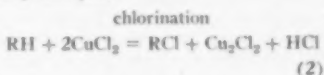
His only example covers the chlorination of methane and he gives no information regarding yields or methods used.

In 1933 Mares (12) discloses the chlorination of benzene with chlorine and oxygen and wherein the hydrogen chloride formed is oxidized, by the catalyst, to chlorine which, being present, chlorinates additional benzene. His catalysts consist of compounds of aluminum, together with copper, iron, or cerium. Copper chloride on pumice is also referred to. Hydrogen chloride is mentioned as being added to the reactants, but, the process would not cover chlorination with hydrogen chloride and oxygen without the addition of chlorine. The following reactions take place stepwise:

$$C_6H_6 + Cl_2 = C_6H_5Cl + HCl \quad (4)$$

$$C_6H_6 + HCl + \tfrac{1}{2}O_2 = C_6H_5Cl + H_2O \quad (5)$$
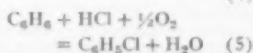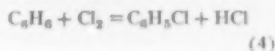
During the past four years the petroleum industry has been taking out

patents on similar modifications of the Deacon process making use of fused, molten catalysts, or the fluid technique and wherein the catalysts circulate in separate zones for chlorination and regeneration. Gorin (11) describes the use of a fused copper chloride: potassium chloride mixture for chlorinating aromatic, or aliphatic, compounds. As described, a melt of cuprous chloride and potassium chloride flows downwards in a tower, at 250-400° C., wherein it contacts a mixture of air and hydrogen chloride and wherein the cuprous chloride is converted to cupric chloride. The hot melt is then pumped to the top of another tower wherein it flows downwards and countercurrent to the hydrocarbon vapor to be chlorinated at 325-500° C. The reduced catalyst is recycled to the top of the first tower. The advantages of this process are claimed to lie in the high hydrogen chloride conversion to chlorine and in the absence of oxygen in the chlorination stage. A catalyst composition for this process is patented by Fontana (10) claiming a catalyst consisting of 25-45 mole % KCl, 5-65 mole % Cu_2Cl_2 and 10-60 mole % $CuCl_2$.

A British patent (16) to Socony Vacuum corresponds in general to the Gorin and Fontana patents, just described, but involves the fluid technique and for the chlorination of saturated hydrocarbons. There is disclosed a 3-step, 3-zone, process consisting of oxidation to CuO:$CuCl_2$, conversion to $CuCl_2$ and chlorination of the hydrocarbon which converts the catalyst to Cu_2Cl_2. In this process copper oxides are suspended on an inert carrier, such as clay, infusorial earth, alumina gel, or silica gel, together with the addition of potassium chloride which is said to aid in the absorption of oxygen.

DeBenedictis & Luten (6) cover a molten catalyst consisting of 30-50 mole % Cu_2Cl_2, 15-25 mole % $PbCl_2$ and 25-45 mole % alkali metal chloride. They claim 98% conversion of hydrogen chloride to chlorine and the chlorination of olefins to the olefin dichlorides.

Riblett (15) discloses the chlorination of methane to methyl-chloride by reaction with hydrogen chloride and oxygen, at 400° C., in the presence of pumice impregnated with cupric chloride.

Cass (1-5) describes the preparation of chlorolefins by the use of a mixture of hydrogen chloride and oxygen, at

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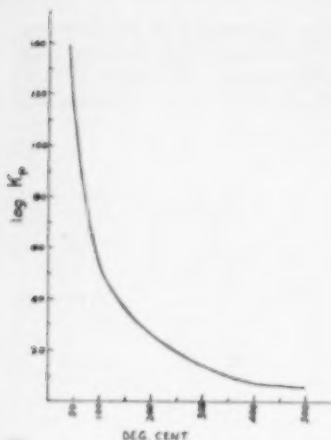
Fig. 1. Deacon Equilibrium Constant According to I. Koppel.

400-500° C., in the presence of pumice, silica gel, or alumina gel, containing a copper salt. Mention is made of predominating chlorine addition products when the temperature is low and of low yields, by pyrolytic reactions, when the temperature is high.

It is believed that these modifications and adaptations of the Deacon reaction, for the chlorination of organic compounds, have been without significant, commercial success because the temperatures, at which the catalysts yield chlorine efficiently, are so high that pyrolysis, decomposition and/or oxidation of the organic becomes a dominating feature; further, conditions often are such that undesirable side reactions take place. In the case of benzene, for instance, the presence of water vapor

leads to the formation of phenol, by hydrolysis of monochlorbenzene formed, which, in turn, is easily chlorinated to chlorphenol. Other products which form are diphenyl, chlordiphenyl and tarry matter.

It is of interest to contemplate the equilibrium constant (K_p) of the Deacon reaction as applying to the above adaptations. The most accurate equation is believed to be that given by I. Koppel, viz.:

$$2Cl_2 + 2H_2O \rightleftharpoons 4HCl + O_2$$

$$K_p = \frac{P^2_{H_2O}P^2_{Cl_2}}{P_{O_2}P^4_{HCl}}$$
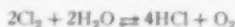
$$\log K_p = \frac{5750}{T} - 2.136 \log T - 8.57 \times 10^{-4}T + 6.83 \times 10^{-6}T^2 + 0.296$$

Calculations for K_p at several temperatures, by the use of this equation, give the curve shown in Figure 1. An inspection of this curve clearly shows that *lower*, rather than *higher*, temperatures favor the release of chlorine in the above reaction. *Catalyst activity*, then, at low temperatures, is essential for the attainment of this desired end.

Dr. Walter H. Prahl, then research chemist for Dr. F. Raschig, GmbH, Ludwigshafen, Rein, Germany, now director of research for Durez Plastics & Chemicals, Inc., North Tonawanda, N. Y., in the early 1930's, initiated a serious study of catalysts for the Deacon reaction for application to the chlorination of benzene, as a necessary step in his development of the Raschig synthetic phenol process. In this synthesis monochlorbenzene is hydrolyzed with water vapor, in the presence of a catalyst, to produce phenol and hydrogen chloride, the latter being recovered in the form of an aqueous solu-

tion, and it was for the purpose of utilizing the recovered acid that work was begun on Deacon catalysts. As a result of this study Prahl developed efficient catalysts which consisted of certain clays, alumina gel, or silica gel, containing copper, together with metals of the groups 3 to 8 of the periodic system. Of prime interest, and importance, was the fact that these catalysts were efficient for the chlorination of benzene at temperatures well below 300° C. (*13-14*).

Prahl soon discarded the usual impregnated carrier type of catalyst for the reasons herein stated. He, then, conceived the idea of a coprecipitated mass wherein, for instance, aluminum hydroxide and copper hydroxide, together with the promotors mentioned, were coprecipitated by adding a solution of copper chloride, and group metal chloride in aqueous hydrogen chloride, to a solution of sodium aluminate, filtering, washing and drying. Catalysts of this type at once yielded chlorine from hydrogen chloride and air, in the presence of benzene vapor, at temperatures as low as 220° C.

The greatly increased activity of coprecipitated catalysts has been disclosed in literature by Adaduron, Krauch and Jaeger. They theorized on catalytic activity by assuming the presence, within the mass, of "active nodes," or "points of activity," upon which catalysis centered, or took place. They submitted, in explanation of the increased activity of coprecipitated catalysts, that a far greater number of the so-called

GENERAL VIEW OF CONTACT CHAMBER

AQUEOUS HCl EVAPORATORS
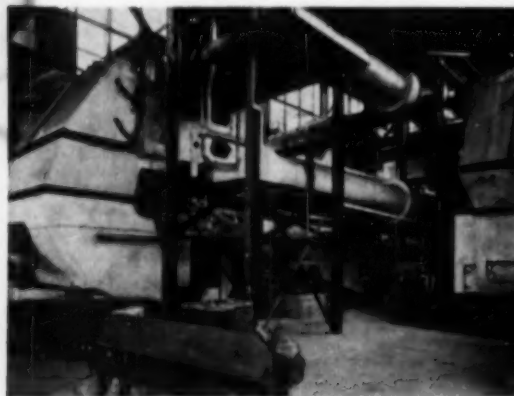
Fig. 2a. Motor on right drives circulating air fan for cooling. Automatic temperature control panel between columns. Contact chamber, proper, constitutes upper portion of assembly shown. Lower duct, entering from right, carries reactions from vapor mixer. Upper duct carries products of chlorination to separation column.

Fig. 2b. Vapor mixer is vertical steel vessel rearcenter. Eight tantalum bayonet heaters shown, four on each of two evaporators.

Three photographs in this article courtesy of Durez Plastics & Chemicals, Inc.

nodes, or points were present in a co-precipitated mass than were present in simple carriers impregnated with a solution of the catalyst proper. The successful work of these men in the field of catalysis is too well known to dwell further upon here.

As Prahl finally developed the process, chlorination consisted in passing a controlled, preheated, mixture of benzene vapor, water vapor, hydrogen chloride and air through his mass at temperatures between 235° C. and 245° C., under which conditions about 98% of the hydrogen chloride was made available as chlorine and monochlorbenzene was almost exclusively formed at conversions of about 10% and with yields of considerably more than 90%. Conversions were held to about 10% by providing excess benzene vapor, in order to suppress the formation of polychlorbenzenes which would be undesirable for the manufacture of phenol. The process was put into small, commercial operation at Ludwigshafen in 1935 in a plant for the manufacture of 5 tons of phenol per day. A large installation was put into operation in 1940 by Durez Plastics & Chemicals, Inc., at North Tonawanda, N. Y., which company acquired U. S. rights to the Raschig process in 1937.

In commercial operation benzene vapor from a still is superheated to about 250° C. in a bank of steel tubes located in a direct-fired furnace. Air is preheated to about 125° C. in a separate bank of steel tubes located in the same furnace. Hydrogen chloride vapor is supplied by evaporation of aqueous acid, contained in acid-brick-lined steel vessels; heat for evaporation is supplied by steam in a number of tantalum bayonet heaters. These reactants, in controlled quantities, are passed through a vapor-mixer consisting of an acid-brick-lined steel vessel which is packed with helical, ceramic tile, its purpose being to assure a uniform mixture of reactants which leave the mixer at about 210° C. to enter the contact mass.

The contact chambers are built of steel and are of cellular construction in which alternate cells are packed with catalyst. The heat of chlorination is removed by air, circulated through air-cooling cells located on each side of each catalyst cell, the cooling air being circulated by a fan. Automatic temperature control is had by providing a standard temperature controller, which coacts with a thermometer bulb in the circulating air stream, and an air-motor damper on the suction side of the fan; thus outside cold air is drawn into the circulating system in proportion to the cooling demand of the converter.

Products of the reaction, consisting of unreacted benzene, water, mono-
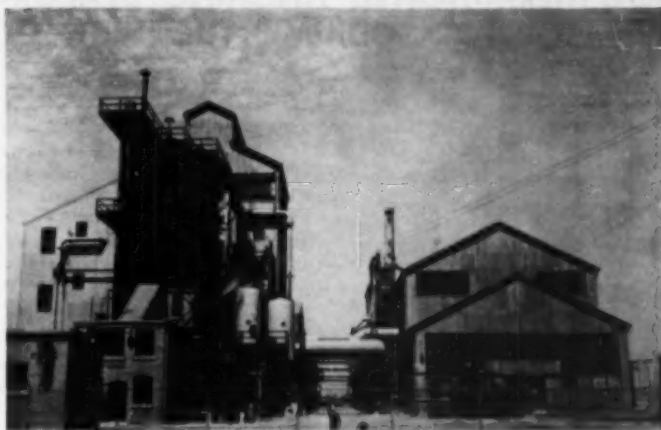
Fig. 3.

Contact chlorination building on right. Condensers, overhead on left, for condensing benzene: water azeotrope. Separation column inside tall building on left.

chlorbenzene, nitrogen and small quantities of dichlorbenzene and excess hydrogen chloride, are roughly separated by fractionation, in an acid-brick-lined packed column which is provided with a controlled reflux of benzene and water. The bottoms from this column consist of a two-phase system—a subnatant layer of weak, aqueous, hydrogen chloride and a supernatant layer of chlorinated benzene in solution in benzene. A vapor overhead from this column, being the azeotrope of benzene and water, is condensed in water-cooled, surface condensers and separated in a continuous decanter for recycle as reflux. The bottoms from the column flow to an acidproof, continuous decanter for the separation of the crude products of reaction which consist of about equal parts by weight of chlorinated benzene and benzene. Being slightly acidic, the organic product is then passed through a continuous alkali washer for neutralization and then separated by continuous, fractional, distillation into benzene, monochlorbenzene and a small amount of crude dichlorbenzene as bottoms.

The process is continuous throughout, is operated by three men a shift and is conducted in ordinary steel equipment except, of course, where aqueous hydrogen chloride is encountered in which instances acid-brick-lined, steel vessels are used.

The above-described improvement in the Deacon reaction has demonstrated that it has been economical in commercial operation since 1940 as a step in the manufacture of synthetic phenol, and, this improvement has already found application in the chlorination of organics other than benzene.

It is pertinent to note that the investigations of the author, thus far, have indicated that the generic reaction $RH + HCl + \frac{1}{2}O_2 = RCl + H_2O$ appears to be a broad one with the proper catalyst and operating technique application.

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DOWTHERM-HEATED FINISHING EVAPOR-
ATOR FOR SODIUM HYDROXIDE

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The Dow Chemical Company, Pittsburg, California

BETWEEN 1926 and 1930, a number of investigations were carried out on the use of diphenyl as a heating medium in cooperation with the Federal Phosphorus Co. (later the Swann Corp.). At this time many possible uses for high temperature heating media were looked into, among them the evaporation of caustic soda to high concentrations. Results of this specific phase of the work were published in a paper by Badger, Monrad, and Diamond (*1*).

In these experiments a vertical forced-circulation evaporator with a single nickel tube ¾ in. I.D. by 12 ft. long was employed. The caustic was recirculated by a pump. The design of the apparatus and the data for the experiments were given in full (*1*). Heat-transfer coefficients were determined up to 92% caustic but, actually, many runs were made in which caustic was finished to 98% NaOH.

The original apparatus, except for the nickel tubes, was built of iron and steel. The iron parts rapidly corroded, and it became necessary to make the vapor head of nickel cast iron, the piping of monel. The circulating pump was nickel cast iron. In this form, the apparatus was run for many months without serious corrosion of the apparatus itself. However, the iron content of the caustic (and presumably the nickel content also) became high, so that the material produced in all these runs was a dark red-brown. It was not attempted at that time to show how high-grade caustic could be made, but merely to prove that the process was feasible and that caustic could be brought to high concentrations with reasonable heat-transfer coefficients. It is interesting to note that the results of this work showed that up to 92%, the caustic film coefficient was so much higher than the diphenyl film coefficient that the diphenyl film coefficient controlled.

In 1929-30, all funds for such experimental developmental work disappeared. At the time the previous experiments were being carried out, Dowtherm was not on the market and, in fact, the present eutectic mixture sold as Dowtherm A had not been developed.

It was recognized that the principal factor in attempting to make a practical process out of this was to improve the quality of the caustic. It was considered that there were no serious mechanical difficulties and no serious heat-transfer difficulties. The question, therefore, became: of what material could the evaporator be made so as to give a satisfactory product?

Behavior of Nickel in Contact with High Concentration Caustic

The problem was taken up by The Dow Chemical Co., and experiments were carried out in nickel beakers under the direction of S. B. Heath. The first experiments, run in open nickel beakers, showed rapid nickel pickup in all cases. Even after recognizing the necessity for avoiding air and oxidizing influences, it was found that all samples of electrolytic caustic available at that time attacked nickel readily as they came up towards finished caustic. One sample of pure caustic was tried, and it showed no attack on nickel.

Because it was considered possible that chlorate, which is present in electrolytic caustic, might be causing the difficulty, attention was directed towards its removal. It was shown that if atmospheric air were excluded and the caustic were free from chlorate, there was zero attack on nickel by caustic soda up to its fusion point. The problem, therefore, became one of chlorate removal.

Some experimentation had been done trying to use silver as a means of holding caustic at high concentrations; but this proved impossible, because the silver was attacked even more rapidly than nickel, although it did not discolor the caustic so badly. The cost of silver apparatus with the replacement rates that were indicated by laboratory corrosion tests would have been prohibitive.

Attempts were made to find methods for reducing chlorate in strong caustic solutions. Obvious reducing agents were tried and found to be without effect. Finally, Mr. Heath and his coworkers evolved a process by which 50% caustic was treated with finely divided iron and carbon, the residual iron and carbon filtered out, and the material blown with air for a considerable length of time to oxidize the dissolved iron. This was satisfactory in that it did give complete removal of chlorate from the caustic solutions and, therefore, it apparently cleared the way for future experiments on the evaporator itself.

Pilot Plant Operation

The pilot plant work was done at The Dow Chemical Co.'s plant at Pittsburg, Calif. In the fall of 1940 an experimental setup was built, with the cooperation of the Swenson Evaporator Co. This was worked on intensively until the fall of 1942, when it was considered that sufficient experience made possible the purchase of a full-scale evaporator. The installation is shown more or less diagrammatically in Figure 1. The major piece of equipment was an evaporator constructed of nickel wherever metal was in contact with caustic. It had a heating surface of 7 nickel tubes, ⅞-in. O.D., 16 gage, 15 ft. long, assembled in a vapor chest of standard 5-in. steel pipe. The heating medium was Dowtherm vapor generated in a 500,000 B.t.u. Dowtherm vaporizer. At the beginning it was intended to run as a forced-circulation evaporator, and, consequently, the evaporator was provided with a return leg and a circulation

Fig. 1. Diagram of Pilot Plant.
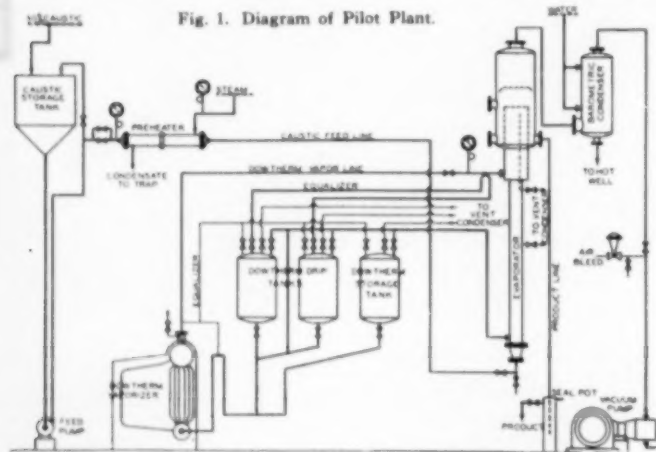
pump. During the first few runs it was found almost impossible to keep this pump in satisfactory operation and, therefore, the pump was eliminated. Attempts were made in one or two runs to operate the evaporator as a natural-recirculation long-tube evaporator, but this also proved to be too difficult. Consequently, from Run No. 8 on, the evaporator was run as a once-through natural-circulation evaporator. This arrangement is still used in the large-scale evaporator in practice.

Considerable concern was felt regarding the possibility of the apparatus freezing up because of the relatively large radiating surface of so small a unit. Consequently, the evaporator body itself and many of the pipe lines were protected by having electric strip heaters tack-welded on at various points and then the insulation put on over these heaters. These heaters proved to be a continual source of trouble due to local overheating. Consequently they had to be eliminated one after the other, and it was only when these heaters were finally gotten under control that the equipment was satisfactory. If nickel is heated to a sufficiently high temperature, it is attacked even by chlorate-free caustic. Hence such hot spots put large amounts of nickel into solution. This was the most serious mistake made in the pilot plant design; and it was soon recognized that a much better method is to jacket the apparatus with Dowtherm.

Seventeen runs were made in all, varying from a few hours up to 200 hrs. In the earlier runs the nickel attack was serious, sometimes giving caustic containing as high as 800 p.p.m. of nickel. The chlorate-removal treatment would be studied or an electric heater removed, and, little by little, the nickel contamination was reduced. During the last half of the final run, No. 17, which lasted for 200 hrs., the nickel content of the finished caustic was 10 p.p.m. or less.

Two runs were also made on caustic potash, and it was concentrated to 91%. In KOH Run No. 2, which ran 85 hrs., there was never more than 1 p.p.m. of nickel in the product, and most of the analyses showed only a trace of nickel.

During this experimental work, the material used was 50% caustic from the regular production of the Pittsburg plant. It was treated for chlorate removal by the use of iron, then blowing to oxidize the iron, and filtering. This had to be done in batches, and the control was not always good. Some batches were chlorate-free; some batches were overtreated and contained excessive amounts of iron; and some batches still had chlorate in them. The material for Run No. 17, the most satisfactory, was practically free from chlorate during the entire period.

A summary of these experimental

runs is given in Table 1.

From the beginning, it was decided to run at a vacuum of 15 in. referred to a 30-in. barometer. The reason for that was based on the data of Figure 2.

The atmospheric boiling-point curve in Figure 2 is taken from the work of von Antropoff and Sommer (4). No data were available at all for any boiling points of concentrated caustic solutions under other than atmospheric pressure. Consequently, the only method available was to assume that the Dühring lines for this material ran through absolute zero and by this means to construct the boiling-point curves for pressures less than atmospheric. It is recognized that this is in error. In particular, the work of Monrad and Badger (2) on the boiling point of caustic solution saturated with sodium chloride shows that in no case do the Dühring lines run through absolute zero. However, for these concentrated solutions, this was the only method available at the time.

On this same chart is plotted the freezing-point solubility curve as given by von Antropoff and Sommer (4). The solid phase is anhydrous sodium hydroxide throughout the range from 76.2% NaOH to 100% NaOH. There is a phase transformation at about 580° F. but the two forms of solid sodium hydroxide represented by this transformation have not been identified. Apparently for any vacuum much greater than 15 in., the freezing point is higher than the boiling point from about 85% to 95%; and therefore some solid sodium hydroxide could separate in the tubes in this range. The curve for the boiling points at 15-in. vacuum is the only one that completely misses the freezing-point curve. The natural-circulation long-tube evaporator is unsuitable for solutions that separate solids in the evaporator, and hence the decision was made to operate with this vacuum.

The choice of 15-in. vacuum for the pilot plant evaporator has proved to be not too far wrong. It has been shown many times that the temperature of the liquid being evaporated in a once-through long-tube vertical evaporator may reach values at some intermediate point in the tube, considerably above the temperature corresponding to the pressure in the vapor head. In the present state of authors' knowledge it is impossible to predict the actual course of the temperature of the liquid in the evaporator under discussion, because of the great change in boiling-point elevation. However, the concentration at which the freezing point approaches most closely the boiling point at 15-in. vacuum must be at some intermediate point in the tube and above the point at which boiling starts; and therefore under a pressure greater than that in the vapor head. Hence 15 in. *in the vapor head* is not necessarily the highest
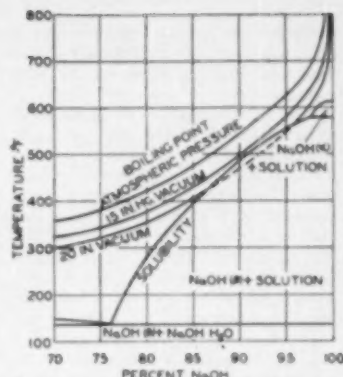
Fig. 2. Boiling Points and Freezing Points of Strong Caustic Solutions.

vacuum at which this evaporator could operate. In practice it is found that a vacuum of 18 in. is perfectly satisfactory. Above 20 in. there is more or less chance of freezing the tube shut, and this will almost always happen at 22 in.

Throughout the experimental work the material fed to the evaporator was 50% caustic, although the plant at Pittsburg contained a steam-heated high concentrator that produced 70-73% caustic. The reason for this was twofold. First, and most important, it had been shown that the chlorate removal took place most readily at 50%. It was not possible to treat enough material in the experimental chlorate-removal equipment to keep the steam-heated high concentrator in continuous operation and thus furnish chlorate-free 70% caustic. Second, the location of the pilot plant evaporator was such that it would have been quite difficult to get caustic from one point to the other. It was believed that if the evaporator could be made to work on 50% caustic, there would be no difficulty whatever in operating later with a feed of 70% or even higher, NaOH.

During all the runs a certain amount of data was taken to make possible a rough estimation of the heat-transfer

TABLE 1.—PILOT PLANT EVAPORATOR RUNS

Run No.	Duration, hrs.	Approx. % NaOH	Approx. Range p.p.m. Ni
2	8.00		--
3	7.75	94	230-880
4	26.50	93	280-470
5	13.75	94	260
6	18.00	93	400-500
7	15.00	93	320
8	27.25	94	90-115
9	117.50	95	125-50
10	......	...	--
			Training new crew
11	13.00	94	84
12	12.75	94	34
13	143.50	94	20-50
14	35.00	91	400-500
15	121.00	92	400-1000
16	150.00	95	40-19
17	199.00	95.5	12-4
		Runs on KOH	
1	187.00	91	20-50
2	85.50	89	1-tr

coefficient. After the evaporator was in good working order a number of formal runs were made to determine the heat-transfer coefficient more accurately.

In these runs, each of which lasted 20 min., conditions were manually controlled and held as constant as possible. Temperatures were read every two minutes. The Dowtherm condensate was collected in a calibrated receiver and read at the beginning and end of each run. Heat transferred was calculated from the Dowtherm condensate collected. Equipment was not available to run a heat balance.

No travelling thermocouple was available, so a temperature traverse of the liquid from bottom to top could not be made. Coefficients are reported in terms of the log mean temperature difference. Since the rise of liquid temperatures along the tube is due mainly to the increase in concentration of the sodium hydroxide solution, its course probably does not follow that assumed in the derivation of the formula for the log mean temperature drop, and so the log mean as has been calculated here is more or less fictitious. However, it may mean a little more than either terminal temperature difference or an arithmetic mean.

The formal heat-transfer determinations are reproduced in Table 2 where

Q/θ = heat transferred, B.t.u./hr.

Δt_{LM} = log mean temperature drop based on (Dowtherm vapor temperature - outlet NaOH temperature) and (Dowtherm vapor temperature-feed temperature)

U_{LM} = over-all heat-transfer coefficient based on Δt_{LM}.

The approximate data taken during ordinary runs NaOH 16, NaOH 17 and KOH 1 were calculated to heat-transfer coefficients. They gave coefficients of a magnitude comparable to those of Table 2, but are not precise enough to warrant reproduction here.

Since the evaporator was operating only under a 15-in. vacuum, it was possible to set it high enough so that the discharge of the concentrated liquor was by gravity. It came down through a nickel pipe ending in a pair of nickel plug cocks, and was drawn into drums for further treatment. Since, in all these experiments the caustic was in bad shape, either due to excess iron from

overtreatment, to nickel from undertreatment, or to a combination of both, it was obviously impossible to pack the product for market. Consequently, the product of all these runs was combined into some of the regular pots in use at the plant and given a treatment. One pot, which was made up entirely of material from the latter half of Run 17 and was finished with the usual sulfur treatment, analyzed about the same as the average production at Pittsburg at that time.

The purpose of the pilot plant work was really primarily to prove that with chlorate-free caustic, a nickel evaporator would function over long periods of time and give a satisfactory product. While it is true that the best product made in the pilot evaporator was still not really marketable caustic without further treatment, nevertheless, it was amply proved that with proper operation of the chlorate treatment of the caustic and the elimination of hot spots due to electric heaters on the pipe lines, caustic sufficiently low in nickel could be made, so that the life of the evaporator would be reasonable and the caustic made could be treated to make a marketable product. It was at that time fully expected that the product of such an evaporator would have to go to the pots for treatment before going to the drums. It was, however, considered that the saving in space, fuel, and labor was sufficient to justify the Dowtherm-heated finishing evaporator, even though the product had to be treated at the end for color and iron.

Preparation for Large-Scale Unit

Although the best results from the pilot plant were far from being as good as had been hoped, it was decided at once to order a unit to handle approximately 60 tons per day. This was ordered from the Swenson Evaporator Co. in 1942, but due to the exigencies of the war situation, was not delivered until late in 1945.

Considerable effort was put on the removal of chlorates from the solutions and on the behavior of nickel and iron in these solutions. This work was done under direction of Dr. W. Hirschkind, of the Great Western Division of The Dow Chemical Co. The reaction between metallic iron and caustic was studied, and the final conclusions were reached:

1. Charcoal was not necessary.
2. Powdered iron would reduce chlorates to a point less than 0.1 p.p.m.
3. So long as any chlorates were present in the solution, iron did not pass into permanent solution.
4. Once the last trace of chlorate was removed, iron went into permanent solution rapidly as ferrous iron.
5. This ferrous iron would react with chlorates, but the state of oxidation of the resultant mixture prevented removal of the iron and, therefore, overtreated and undertreated material, when mixed, did not give properly treated material.
6. A considerable change in the oxidation-reduction potential of the solution occurred at the point where the chlorates disappeared, and it was found that this could be used as a means for controlling the iron dosage.

This work resulted in the development of a piece of apparatus that has been patented (3). The exact mechanism of the reduction of chlorates by iron is discussed at length in this patent. This method of chlorate removal was provided in the installation built in 1945-46.

In the course of about a year's experience with this apparatus, it was found that mechanical complications in connection with the control were so serious that precise control by this method was difficult; with the result that while the apparatus operated for more than a year, it was found that it produced both under- and overtreated material too frequently. The process has, therefore, been abandoned.

Further work was then undertaken in 1946-47, looking to new methods for the control of chlorates. It was finally found that certain compounds could be used for the quantitative reduction of chlorates in caustic soda solutions, and a method based on this has been worked out. The method is greatly simplified in that no treatment apparatus is required. The reagent is simply added to the caustic in the feed tank of the Dowtherm-heated evaporator. The exact methods and materials involved are covered by patent applications now pending.

Full-Scale Equipment

The essential features of the evaporator supplied by the Swenson Evaporator Co. and installed in the winter of 1945-46 are shown in Figure 3. It is a vertical-tube long-tube once-through natural-circulation evaporator with an external vapor head and a secondary entrainment separator. Discharge is by gravity, and the apparatus is operated at approximately 15-in. vacuum. The heating surface consists of 14-gage nickel tubes 7/8-in. O.D. x 20 ft. 0 in. long, and all parts in contact with caustic are of nickel. This evaporator was first put into operation in the spring of 1946, and on March 15, 1946, turned out its first batch of finished caustic.

During the past two years several mechanical difficulties appeared. Many of these were due to features in the

TABLE 2.—HEAT-TRANSFER RUNS

Run No.	Q/θ	Dowtherm Vapor Temp.	Exit NaOH Temp.	Feed Temp.	H₂O Evapd. lb./hr.	Δt_{LM}	U_{LM}
HT-1	144,000	561	547	343	98	74.5	80
HT-2	159,000	550	545	346	81	73.1	90
HT-3	148,500	546	534	343	78	67.8	88
HT-4	143,000	544	534	345	75	63.4	94
HT-5	189,500	573	559	359	135	78.2	100
HT-6	147,000	570	560	341	135	70.0	87
HT-7	204,000	571	559	341	122	73.9	115
HT-8	176,500	558	549	340	117	65.5	113
HT-9	146,000	559	548	344	108	68.7	88
HT-10	193,000	555	545	341	127	67.8	117
HT-11	179,000	557	548	341	132	65.3	114

design which have since been rectified or will be rectified with full confidence in future installations. In particular, in the original design there were not enough provisions to take care of expansion; with the result that welds failed and leaks developed. Because it was thought there might be leaks where air could enter and thus cause nickel contamination, the whole apparatus was welded up without any joints, which made repairs unduly troublesome and expensive. However, the greatest difficulty turned out to be due to the irregularities of the chlorate treatment. When undertreated material ,was fed, there was a serious attack on the nickel. When overtreated material was fed, the tubes became plugged with an iron-containing deposit. In the summer of 1947 the tubes finally failed and the evaporator had to be retubed. During this period, the evaporator finished about 6800 tons of caustic soda, yielding a product having an NaOH concentration of from 96 to 97%. The nickel content was in the order of 5 to 25 p.p.m., although during an appreciable part of the operation it was held below 5 p.p.m. Since, due to the erratic behavior of the chlorate treatment, this caustic always contained iron, it was necessary to send it to the pots for treatment, and, consequently, the rather high nickel content did not make any difficulty. The pots also accomplished the removal of the last of the water, so that the concentration of 96-97% was satisfactory.

One problem in connection with the performance of this commercial evaporator has been the fact that plant requirements for finishing capacity have been too small to keep the Dowtherm-heated evaporator in operation continuously. Consequently, its operation for the past two years has been irregular. For long periods it was operated only three days a week. At the present time, the operating crew feels that the apparatus is completely reliable and almost completely automatic.

With the change in chlorate treatment, a considerable change in the quality of the caustic has occurred. The operation of the steam-heated high concentrator, which carries caustic to approximately 70% in the Dow plant at Pittsburg, is such that the caustic leaving this evaporator contains from 2 to 5 p.p.m. of nickel. Over that period of time during which the new reducing agent has been used, it has become established that the pickup in the Dowtherm-heated evaporator is of the order of 1 p.p.m. or less. The intermittent nature of the operation of the Dowtherm-heated evaporator has prevented a more accurate appraisal of this, but it is certain at the present time that the evaporator can be operated in practice so as to contribute less than 1 p.p.m. of nickel to the finished material.

Fig. 3. 75-Ton Plant Scale Evaporator.
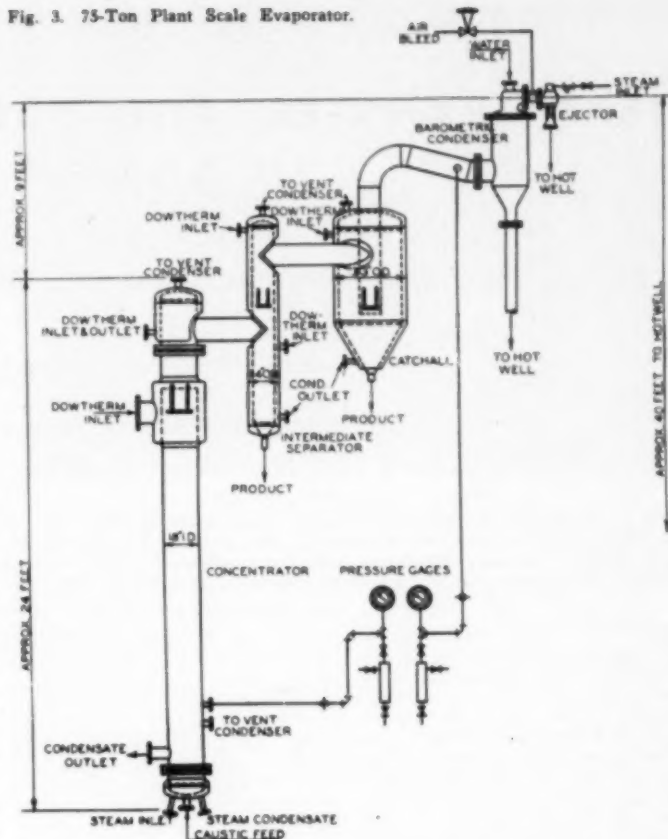
The evaporator was designed to handle 75 tons/day. It has been operated at capacities up to almost 115 tons/ day, but at this capacity the loss by entrainment is serious. Certainly the evaporator can operate continuously at 60 tons/day, which is the present rate at which it is ordinarily used.

Dowtherm pressures have been gradually raised until the Dowtherm vaporizer is now operating at 700 to 710° F. Under these conditions the evaporator will produce a caustic containing more than 75% Na_2O. Two analyses that have been produced recently show respectively 99.70 and 99.73% total solids in the finished product. Because the setup at Pittsburg is such that it is more convenient to pack the material out of the pots, the product is still run to the pots and packed out of them. This also makes it possible to run the evaporator 24 hrs. a day but to carry out the packing only on the day shift.

At the present time the ordinary natural-circulation Dowtherm vaporizers are not expected to operate at temperatures as high as 715° F. This is giving, as noted above, about 0.3% moisture in the final product, and since at these concentrations the boiling point of caustic rises rapidly with increase in caustic concentration, a considerable increase in the temperature of the heating medium is desirable. In two Dowtherm vaporizers, one of them representing a design in actual service, the other representing a new design not yet on the market, forced circulation is employed instead of natural circulation. In such cases it seems possible to raise the Dowtherm temperature to as high as 760° F. without serious decomposition of the Dowtherm. Such a vaporizer attached to an evaporator of the type in question would have a considerable advantage.

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(End of Symposium)

HEAT TRANSFER AND PRESSURE DROP IN ANNULI

Measurements on Plain and Transverse Fin Tubes Using Water

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One plain and six fin tubes, 9 ft. long, were tested in the range of Reynolds numbers from 1000 to 70,000 in the annulus. The mechanism of water flow between the fins was observed. The correlation of heat transfer includes factors to account for fin height and fin spacing.

S ATISFACTORY relationships for predicting pressure drop and heat transfer in annuli require the length term which defines the geometry of the annulus. The heat transfer and pressure drop are a function of the dimensions of both tubes making up the annulus. In the case of an annulus with a smooth tube as the inner tube, it has been found that the diameter to use is $D_E = D_2 - D_1$. The equivalent diameter, D_E, is based on the hydraulic radius, i.e.,

$$D_E = 4r_h = \frac{(\pi)(D_2{}^2 - D_1{}^2)}{(\pi)(D_2 + D_1)}$$
$$= D_2 - D_1 \qquad (1)$$

Pressure drop in annuli with smooth tubes has been studied (1-5, 9, 15, 23, 27).

Using the equivalent diameter, D_E, the Fanning friction factor in annuli is given by Equation (2);

$$\frac{dP}{dL} = \frac{2fV^2\rho}{g_c D_E} \qquad (2)$$

The empirical relationship between the friction factor and the Reynolds number is generally given in the form of Equation (3);

$$f = k'(Re)^n \qquad (3)$$

Values of the constant k' range from 0.056 to 0.133 with 0.076 being the usual value. The value of the exponent n is generally 0.25. Davis (6) has studied all data for pressure drop during tur-

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bulent flow in annuli and gives the equation:

$$f = C(Re)^{-0.25}(D_2/D_1)^{-0.1} \qquad (4)$$

The effect of the diameter ratio is seen to be small. Most published data on pressure drop in annuli agree with Equation (3) with the value of k' given by Equation (5) and with $n = -1.(16)$

$$k' = \frac{16(D_2 - D_1)^2}{D_2{}^2 + D_1{}^2 - \frac{D_2{}^2 - D_1{}^2}{\ln(D_2/D_1)}} \qquad (5)$$

Pressure drop in annuli containing fin tubes has been studied (9, 10, 15, 17). The bulk of the data indicates that with longitudinal fin tubes in annuli, the friction factor agrees approximately with that for plain tubes in annuli when using an equivalent diameter equal to four times the hydraulic radius. The length term which is used to define the equivalent diameter of an annulus with transverse fin tubes has been arbitrarily defined as $D_E = D_2 - D_1$, where D_2 is I.D. of outer tube and D_1 O.D. of the fin.

Heat transfer in annuli containing

smooth tubes has also been studied (4, 7, 9, 11, 18-20, 24, 28). Davis (6) made a study of all data on the heat transfer in annuli and recommends the following equation:

$$\frac{hD_E}{k} = .031\left(\frac{D_E V\rho}{\mu}\right)^{0.8}\left(\frac{C\mu}{k}\right)^{\frac{1}{3}}\left(\frac{\mu}{\mu_w}\right)^{0.14}\left(\frac{D_2}{D_1}\right)^{.15}\left(\frac{D_E}{D_1}\right)^{0.20} \qquad (6)$$

Wiegand (25) also made a study of all data and recommends the following equation:

$$\frac{hD_E}{k} = 0.023\left(\frac{D_E V\rho}{\mu}\right)^{0.8}\left(\frac{C\mu}{k}\right)^{m}\left(\frac{D_2}{D_1}\right)^{0.45} \qquad (7)$$

The value of m in Equation (7) is 0.3 for cooling and 0.4 for heating.

Heat transfer in annuli containing fin tubes has been studied (9, 10, 12, 17). For the heat transfer from fin tubes in annuli the data have been correlated by equations similar in form to Equations (6) and (7). However, no general correlation has been given for heat transfer from fin tubes which considers the effect of tube dimensions such as fin height and fin spacing.

Experimental Equipment

A photograph of the equipment used is shown in Figure 1. The heat exchanger is 9 ft. long and consists of a clear plastic outer tube and copper plain or finned inner tubes. Systems were provided for circulating hot water through the inner tube and cold water through the annulus.

The outer pipe of the annulus consisted of two 52-in. lengths of cast Plexiglas tubing joined at the middle. The I.D. of this tubing was 2.240 ± 0.005 in. The diameter at any cross section did not vary by more than 0.001 in. The plastic tubing was mounted between an entrance and exit section which held the inner tube. The entrance section shown in Figure 2 is made of two 4-in. cast-iron blind flanges bolted to each other with a 2.75-in. section of 6-in. pipe between them. The plastic tubing is connected to the flange, A, by means of the plastic flange, H, which is cemented to the plastic tubing, and the steel ring, L, which

is bolted over flange, H, to flange, A. Flange, A, is rounded at the entrance into the annulus. The fluid enters the section by means of four pipes, E, which are screwed into flange, A′. Two 70-mesh screens are placed beyond the pipes, E, to act as a short calming section.

The inner tube of the annulus is soldered to the brass bushing, B, which is held in flange, A′, by a packing and a packing gland. The inner end of the brass bushing, B, was tapered at an angle of 30° so as to conform somewhat to the stream lines of the entering fluid. This entrance section was designed to minimize disturbances to the fluid as it entered the annulus. The exit section of the annulus was similar to the entrance section except that the fluid left by way of one pipe screwed into the 6-in. pipe section.

Figures 3a. and 3b. show flow sheets of the hot- and cold-stream systems. The hot system was heated by means of live steam injected directly into the circulating stream. The cold stream was supplied with water from a constant level storage tank so that steady flow could be attained.

The plain tube and six transverse helical fin tubes were tested during the course of the investigation. All tubes were made of copper. Dimensions of the tubes were determined by a cathetometer accurate to 0.001 in. Tables 1 and 2 give the dimensions of the various tubes and annuli.

The pressure drop in the annulus was measured by means of three pressure taps; tap No. 1 was located 2 in. from the entrance to the annulus; tap No. 2 was located 48 in. from tap No. 1 and tap No. 3 was located 49 in. from tap No. 2. The pressure tap was a 1/16-in. hole drilled in the wall of the plastic tubing. A copper tubing connection was cemented over this hole and copper tubing lead from the pressure tap to the manometers.

Cold-stream temperatures were measured by means of thermometers graduated in 1/10° F. divisions and hot-stream temperatures were measured by thermometers graduated in 1/10° C. divisions. All flow rates were measured with calibrated orifices. All pressure drops greater than 1 in. of fluid were read on vertical double liquid manometers. The sensitivity of these manometers varied depending on the heavy fluid which was used in them. Low pressure drops of less than 1 in. of fluid were determined on a micromanometer accurate to ±0.002 in. The micromanometer was built from plans given by Rothfus (23).

Experimental Data

The quantitative experimental data consist of heat-transfer and pressure-drop data in annuli containing the various tubes described in Table 1. A summary of the conditions for measurement of isothermal pressure drop is shown in Table 3. Pressure drops were also measured when heat transfer was taking place in the annulus and it was thus possible to compare isothermal and nonisothermal friction factors. Isothermal pressure drops were determined over the whole length of the annulus and also over the last half of the annulus. Thus, it was possible to determine whether there was any entrance effect due to the liquid entering the annulus.

The purpose of the heat-transfer experiments was to determine the heat-transfer coefficients on the outside surface of the inner tube in the annulus. Since only overall coefficients were measured, it was necessary to determine the heat-transfer coefficients inside the tube. This was done by
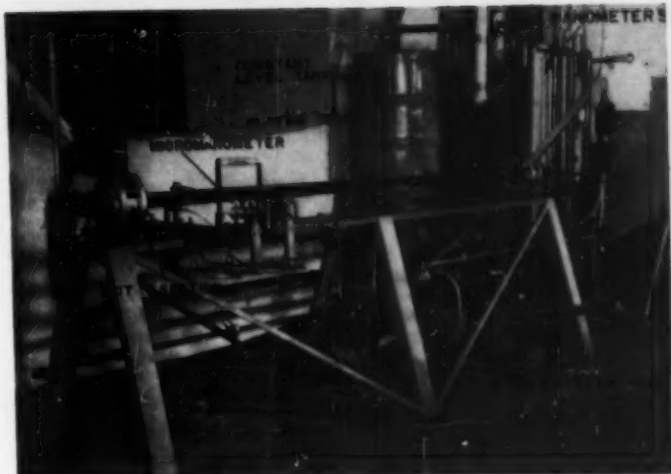
Fig. 1. Experimental Equipment.

making a series of heat-transfer tests in which the cold annular fluid has a constant flow rate and the velocity of the hot inner fluid was varied. Data from such a test could be used to draw a Wilson plot (26) and thus one could calculate the inside coefficients and determine an equation for predicting them. A summary of the conditions at which the heat-transfer measurements were made is shown in Table 4.

Qualitative data, obtained during the investigation, included photographs of the flow patterns which occurred in the fin spaces during streamline and turbulent flow. By injection of methylene blue dye into the flowing stream in the annulus 12 in. from upstream end, it was possible to observe the turbulence in the fin spaces. A series of

photographs of the flow patterns in the fin spaces was taken such as those shown in Figure 4 for tube number 2. From these patterns it was possible to make some deductions regarding the mechanism of heat transfer from fin tubes.

Velocity profiles were determined for the annuli and are reported in detail in the thesis (14).

Discussion of Data

Flow Patterns Between the Fins. Flow patterns between the fins were studied on fin tubes Nos. 2 to 6 over a range of Reynolds number from 500 to 20,000. This includes both the stream-
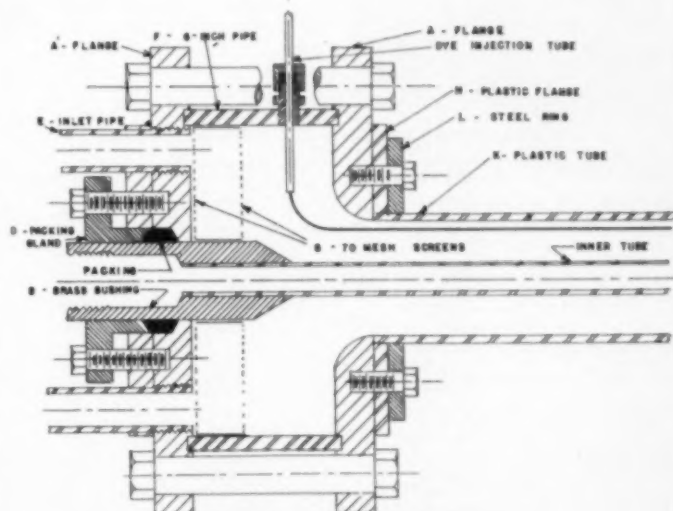
Fig. 2. Detail of Entrance Section.
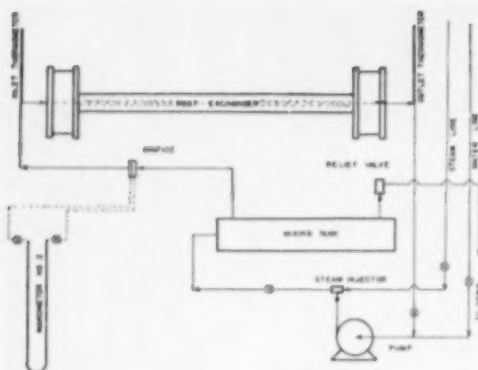
Fig. 3a. Schematic Flow Sheet of Hot Stream System.
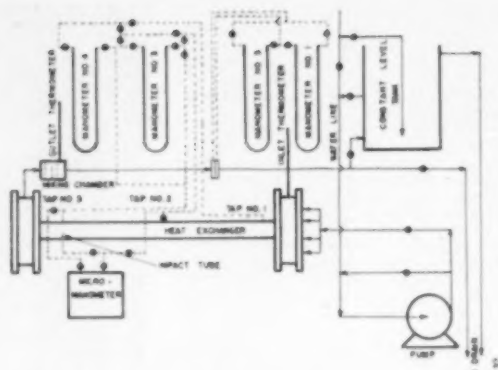
Fig. 3b. Schematic Flow Sheet of Cold Stream System.

TABLE 1.—DIMENSION OF TUBES

Tube	Fins/ in.	Diameter of Fins D_o in.	Root Diameter D_o in.	Fin Thickness t in.	Fin Spacing S in.	Fin Height W in.	Finned Length ft.	Area of Primary Surface sq.ft.	Area of Extended Surface sq.ft.	Total Outside Area sq.ft.	Inside Diameter D_i in.	$\frac{A_o}{A_i}$
Plain	0	.623	.623	0	0	00	9.0	1.475	0	1.475	0.493	1.268
Fin Tube No. 1	11.32	.759	.623	.0243	.0641	.0673	9.0	1.065	2.913	2.978	0.509	3.32
Fin Tube No. 2	3.98	1.050	.664	.029	.222	.193	9.0	1.384	3.280	4.664	0.517	3.83
Fin Tube No. 3	9.12	1.031	.648	.026	.098	.191	9.0	1.207	6.541	7.748	0.510	6.45
Fin Tube No. 4	4.19	1.241	.655	.0241	.214	.293	9.0	1.387	5.639	7.026	0.514	5.80
Fin Tube No. 5	5.85	1.295	.649	.0255	.146	.323	9.0	1.301	8.884	10.185	0.544	7.95
Fin Tube No. 6	9.02	1.319	.639	.0216	.1019	.341	9.0	1.237	12.85	14.05	0.533	11.23

TABLE 2.—DIMENSIONS OF ANNULI

Inner Tube	Equivalent Diameter D_s ft.	$\frac{S}{D_s}$	$\frac{W}{D_s}$	Roughness of Inner Tube $\frac{W}{D_i}$	Volume of Space Between Fins (V_F) cu.ft./ft.	Volume of Free Flow V_{FF} cu.ft./ft.	$\frac{V_F}{V_{FF}}$	$\frac{1A_o}{kA_m}\times 10^6$ B.t.u. (hr.)(sq.ft.) (°F.)
Plain	0.1347	0	0	0	0	.0253	0	.028
Fin Tube No. 1	0.1233	.0596	.0455	.0888	.00286	.0250	.115	.071
Fin Tube No. 2	0.0991	.1460	.1624	.184	.00560	.0246	.228	.088
Fin Tube No. 3	0.1007	.0812	.1582	.185	.00506	.0244	.208	.149
Fin Tube No. 4	0.0832	.2142	.294	.236	.00778	.0244	.819	.137
Fin Tube No. 5	0.0787	.1548	.342	.250	.00811	.0241	.338	.144
Fin Tube No. 6	0.0767	.1107	.3605	.269	.00824	.0239	.346	.225

S = Fin spacing
W = Fin height

TABLE 3.—SUMMARY OF ISOTHERMAL PRESSURE-DROP DATA

Inner Tube	Reynolds No. Range	Range of Water Temp. in Annulus, °F.	No. of Tests
Plain Tube	11,000-62,000	46-65	29
	840-9800	46-49	22
	12,000-62,000	59-87	26
	800-11,000	46-56	24
Fin Tube No. 1	540-7700	44-49	34
	65,000-65,000	46-67	30
Fin Tube No. 2	500-21,000	45-48	48
	6500-41,000	45-46	15
	3200-50,000	43-60	28
Fin Tube No. 3	4200-42,000	43-	11
	10,000-42,000	46-48	33
	6200-74,000	46-68	24
	470-4900	46-49	30
Fin Tube No. 4	3100-42,000	48-49	34
	240-3000	48-52	27
	1800-72,000	49-90	22
Fin Tube No. 5	2700-42,000	50-51	36
	350-3000	50-57	25
	2400-42,000	50-53	18
Fin Tube No. 6	1400-52,000	52-54	36
	370-2800	52-55	24
	1100-12,000	52-54	19

line and turbulent regions of flow. Figure 5 shows diagrammatically the flow patterns for all tubes at various flow rates as indicated by photographs similar to Figure 4.

In the viscous region of flow the blue dye is in the form of a thin filament and does not go into the spaces between the fins. This indicates that the fluid between the fins is substantially motionless during streamline flow. As the flow rate increases the dye loses its filament-like character, indicating that there is turbulent flow in the annular space. The dye is also drawn into the fin spaces and forms a circular pattern as shown in Figure 4b. These eddies or vortices rotate in a direction so that the part which is in contact with the main stream goes the same direction as the main

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stream. When these circular eddies first form they are intermittent and only become steady as higher flow rates are encountered.

An inspection of Figures 4 and 5 reveals that for turbulent flow in the annulus, there are a number of different flow patterns attainable between the fins and the type of flow pattern appears to be dependent on the fin height to fin-spacing ratio, (W/S). For fin tube No. 2, $W/S = 0.87$ and the flow pattern is one circular eddy between the fins.

Results indicate that the fin height to fin-spacing ratio can be used to predict the flow patterns which occur between fins during turbulent flow in the annulus. For $W/S = 0.76$ to 1.35, one eddy occurs. This eddy is usually circular but becomes elongated at $W/S = 1.35$. For $W/S = 1.95$ to 2.2 two circular eddies form between the fins. They rotate in opposite directions. For $W/S = 3.35$, one circular eddy forms at the outer edge of the fin space but in the rectangular space between the outer eddy and the tube wall there are no steady circular eddies formed.

These results on the study of flow patterns are in substantial agreement with preliminary studies made on two-dimensional models (14).

Pressure Drop in Annuli

All the pressure-drop data that were taken during the runs shown in Table 3 are used in Equation (2) to calculate the friction factor. A primary analysis of the pressure-drop data involved a comparison of the pressure drop over the whole length of the annulus compared with the pressure drop over the last half of the annulus. This comparison for turbulent flow is shown in Figure 6, where the ratio of the friction factor for

the entire section (f_{1-3}) to the factor for the last half (f_{2-3}) is plotted vs. the Reynolds number.

Figure 6 shows that for the plain tube and fin tube No. 1 f_{2-3} and f_{1-3} are substantially equal, indicating that there are no entrance effects due to the fluid entering the annulus. If there were end effects present, f_{1-3} would be different from f_{2-3} and it might be expected that the extra disturbance due to the fluid entering the annulus would cause a greater pressure drop, thus making f_{1-3} greater than f_{2-3}. However, in the case of fin tubes Nos. 2 to 6 (inclusive) f_{1-3} is less than f_{2-3} by as much as 5% for some tubes. This could be explained on the basis of the flow of the fluid between the fins. The eddies occurring between the fins will cause a large proportion of the pressure drop in the annulus and there may be a certain length of time required to establish the flow patterns between the fins. Thus, the pressure drop over the first foot of annulus would not be as great as over the second or third foot of annulus. The value of f_{1-3} would then be less than f_{2-3} because tap No. 1 was located 2 in. from the annulus entrance.

Figure 7 is a plot of all isothermal pressure drop data (f_{2-3}) for streamline and turbulent flow. Considering the streamline flow data first, Figure 7 shows that all data for all the tubes can be represented by a straight line expressed by the following equation:

$$f = 24.6(Re)^{-1} \qquad (8)$$

The constant k' which can be calculated theoretically from Equation (5) is listed in Table A for each tube. The agreement with the curve drawn through all the experimental data using a constant of 24.6 is good.

Fig. 4. Flow Patterns for Fin Tube No. 2. From top to bottom: a. $V = 0.09$ ft./sec. $Re = 632$. b. $V = 0.211$ ft./sec. $Re = 1480$. c. $V = 0.724$ ft./sec. $Re = 5070$. d. $V = 1.24$ ft./sec. $Re = 10,400$.

TABLE A

Inner Tube	Calculated Value of k'
Plain Tube	23.3
Fin Tube No. 1	23.4
Fin Tube No. 2	24.0
Fin Tube No. 3	24.2
Fin Tube No. 4	24.2
Fin Tube No. 5	23.0
Fin Tube No. 6	23.8

Fig. 5. Sketches of Flow Patterns Between Fins.
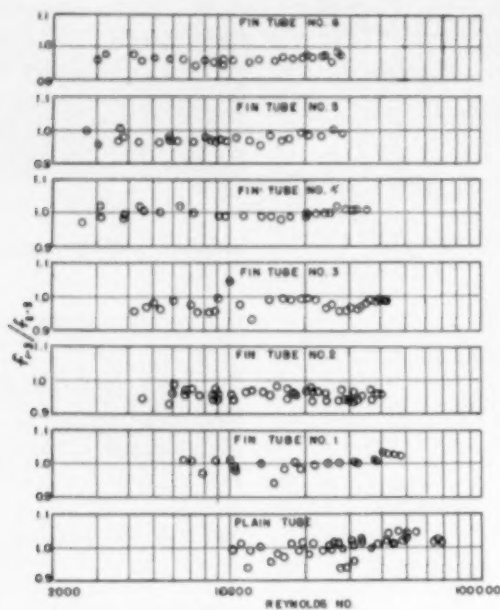
Fig. 6. Comparison of f_{1-2} and f_{2-b}.

each tube. For the plain tube, the friction factor for $10{,}000 < Re < 100{,}000$ is given by the equation:

$$f = 0.073(Re)^{-0.29} \qquad (9)$$

This is in good agreement with the results of other workers.

The set of curves shown in Figure 7 are similar to the friction factor curves obtained by Nikuradse (21) for circular pipes of varying roughness. Nikuradse found that in the streamline region, the friction factor was independent of the roughness while in the turbulent region there was an individual curve for each roughness which he studied. The roughness of each fin tube, which was tested in the present investigation, is given in Table 2. The roughness is expressed as the ratio of the fin height to the fin diameter, (W/D_1). Fin tubes Nos. 2 and 3 have the same roughness but have different friction factor curves.

It thus appears that the fin spacing has an influence on the friction factor and in order to take this variable into account, the quantity V_f/V_{FF} was determined for each tube. The term V_f is the volume of fin space per foot of annulus and V_{FF} is the volume of annular space per foot of annulus. Physically, V_f/V_{FF} expresses the fraction of the total annular fluid which is between the fins. Since a considerable portion of the pressure drop in annuli containing fin tubes is caused by the fins, the term V_f/V_{FF} should express this pressure

It is concluded that for annuli containing transverse fin tubes the pressure drop during streamline flow is the same as when a plain tube of the same diameter as the fins is the inner tube.

In the region of turbulent flow, however, the annuli containing fin tubes have a much higher friction factor than annuli containing plain tubes. There is an individual friction factor curve for

TABLE 4 — SUMMARY OF ANNULAR HEAT TRANSFER DATA

Run No.	COLD STREAM		HOT STREAM			
	Reynolds No. Range	Temperature Range ° F.	Reynolds No. Range	Temperature Range ° F.	Log Mean Temperature Diff.—° F.	No. of Tests
Plain Tube						
PH1	9700–50,000	47–51	159,000–162,000	177–179	127–132	9
PH2	23,400		66,000–154,000	161–172	113–133	5
PH3	50,000		53,000–147,000	137–147	90–98	6
PH4	2600–76,000	47–79	123,000–168,000	138–168	79–112	14
Fin Tube No. 1						
F1H1	1800–50,000	47–61	82,000–128,000	95–128	39–70	19
F1H2	20,000	49	70,000–146,000	136–159	85–105	5
F1H4	445,000	47	58,000–114,000	107–132	59–81	5
F1H5	56,000–77,000	59–63	110,000–120,000	110–120	35–51	5
Fin Tube No. 2						
F2H1	1100–73,000	48–85	86,000–165,000	104–147	30–79	23
F2H2	3720	48	61,000–135,000	121–157	72–104	9
F2H3	20,400	50	60,000–128,000	123–159	72–104	8
F2H4	28,900	48	63,000–127,000	120–149	71–97	7
F2H5	33,200	47	60,000–104,000	114–146	66–95	7
F2H6	1000–48,000	57–79	77,000–136,000	90–120	14–65	17
Fin Tube No. 3						
F3H1	900–73,000	47–86	90,000–156,000	900–148	25–74	31
F3H2	52,500	49	61,000–135,000	121–159	71–104	8
F3H3	23,300	50	63,000–151,000	129–164	76–108	8
Fin Tube No. 4						
F4H1	900–71,000	51–89	73,000–147,000	89–148	15–68	33
F4H2	33,500	53	60,000–132,000	122–154	67–98	8
F4H3	20,000	56	63,000–148,000	130–165	74–106	8
Fin Tube No. 5						
F5H1	1200–68,000	53–68	69,000–142,000	89–139	10–61	31
F5H2	35,000	53	82,000–117,000	114–140	59–81	9
F5H3	21,000	57	55,000–187,000	120–146	62–85	9
F5H4	1500–1900	66–72	56,000–68,000	80–96	13–26	4
Fin Tube No. 6						
F6H1	2500–66,000	54–87	70,000–142,000	91–125	25–54	26
F6H2	36,000	54	54,000–126,000	108–141	50–79	9
F6H3	18,000	59	57,000–136,000	117–148	57–94	9
F6H4	800–2000	72–77	65,000–73,000	85–103	11–20	7

drop. It is seen from Figure 7 that the position of the friction-factor curve for each tube is consistent with the value of V_f/V_{FF} for each tube even though a cross plot does not give a single smooth curve.

Isothermal and nonisothermal friction factors for turbulent flow are compared in Figure 8. Only for fin tube No. 1 and the plain tube are the nonisothermal friction factors less than the isothermal friction factors. Perry (22) reports that for circular pipes the nonisothermal friction factor is 2 to 5% lower than the isothermal friction factor. This is true also in the present case for the annulus containing the plain tube.

Heat-Transfer Coefficients Inside Tubes. All runs shown in Table 4 for which the cold stream Reynolds number is constant gave Wilson plot data as illustrated in Figure 9. It is assumed in drawing the Wilson plot that the inside heat-transfer coefficient can be expressed by the following equation:

$$\frac{h_i D_i}{k} = c \left(\frac{D_i V_i \rho}{\mu}\right)^{0.8} \left(\frac{C\mu}{k}\right)^{0.3}$$

(10)

Thus for a constant annular flow rate and temperature and moderate temperature variation of the inside fluid the following equation applies:

$$\frac{1}{U_o} = \frac{c'}{V_i^{0.8}\theta_e} + c''$$

where:

θ_e = temperature correction
$\qquad = 1 + a(t_b - t')$

a = rate of change of
$\qquad k \left(\frac{\rho}{\mu}\right)^{0.8} \left(\frac{C\mu}{k}\right)^{0.3}$
$\qquad$ with temperature

t_b = some base temperature

t' = temperature being considered

Equations for the heat-transfer coefficients inside the tubes were obtained in the form of Equation (10) and the values of the constant (c) are given below:

Inner Tube	Value of c
Plain Tube	0.0241
Fin Tube No. 1	0.0252
Fin Tube No. 2	0.0264
Fin Tube No. 3	0.0250
Fin Tube No. 4	0.0270
Fin Tube No. 5	0.0420
Fin Tube No. 6	0.0335

For the plain tube good agreement is obtained with the usual Dittus-Boelter equation where $c = 0.023$. The higher values of c for the fin tubes probably is caused by the grooves present on the inner surface of these tubes. These grooves are caused during the manufacture of the fin tubes and act as turbulence promoters to increase the heat-transfer coefficients inside the high fin tubes.

Heat-Transfer Coefficients in Annuli. The experimental heat-transfer data for the plain tube are plotted in Figure 10

as $(Nu/Pr^{0.333})(\mu/\mu_w)^{0.14}$ vs. Re and Figure 11 as $Nu/Pr^{0.4}$, vs. Re. The line representing the Davis (6) equation (Equation (6)) for this annulus is shown in Figure 10 and the line representing the Wiegand (24) equation (Eq. (7)) is shown in Figure 11. The experimental data show fair agreement with these two equations which represent the bulk of the published experimental data. Data shown in Figures 10 and 11 represent two different runs made on different days.

The heat-transfer coefficients on the transverse fin tubes were calculated

Fig. 7. Experimental Friction Factors in Annuli.
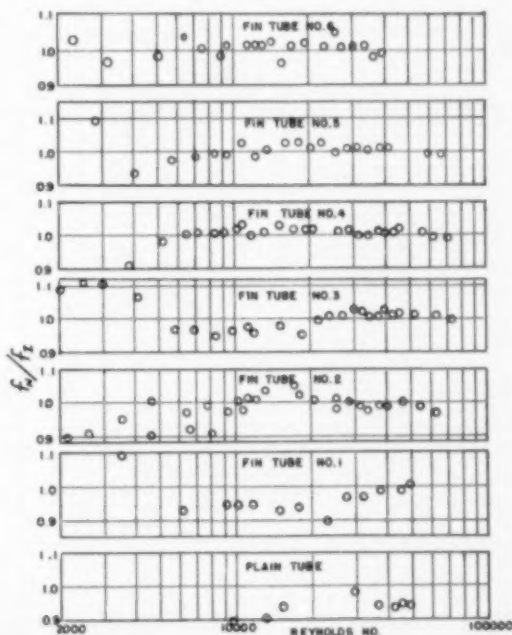
Fig. 8. Comparison of Friction Factor With Heat Transfer to Factor for Isothermal Flow.

Fig. 9. Wilson Plot.

this term was found, it was necessary to know the fin efficiency to determine the true heat-transfer coefficient, h_E. The fin efficiency, ϕ, is a function of h_E and also the dimensions of the fins. Gardner (8) has published curves by which the fin efficiency is obtained. The fin efficiency is used to calculate the effective area, i.e.,

$$A_{EFF} = A_p + \phi A_f \qquad (13)$$

The calculation of h_E from the term $A_o/h_E A_{EFF}$ is a trial-and-error calculation.

Heat-transfer coefficients on the fin tubes are plotted in Figures 12-14, where $Nu/Pr^{0.4}$ is plotted vs. Re. The diameter term used in both Nu and Re is $D_E = D_2 - D_1$. Data for each tube are represented by a straight line in the region of $Re > 6000$. The equation of this line for each tube is given in Table B.

If the heat-transfer coefficient on fin tubes in annuli is a function of the various dimensions which describe the

from over-all heat-transfer coefficients by the following equation:

$$\frac{1}{U_o} = \frac{A_o}{h_i A_i} + \frac{lA_o}{kA_m} + \frac{A_o}{h_E A_{EFF}} \qquad (12)$$

The last term of Equation (12), $A_o/h_E A_{EFF}$, is the reciprocal of the apparent heat-transfer coefficient. Once

TABLE B

Inner Tube	Equation of Lines, (Figs. 12, 13, 14)
Fin Tube No. 1	$Nu = 0.031(Re)^{0.8}(Pr)^{0.4}$
Fin Tube No. 2	$Nu = 0.030(Re)^{0.8}(Pr)^{0.4}$
Fin Tube No. 3	$Nu = 0.026(Re)^{0.8}(Pr)^{0.4}$
Fin Tube No. 4	$Nu = 0.026(Re)^{0.8}(Pr)^{0.4}$
Fin Tube No. 5	$Nu = 0.018(Re)^{0.8}(Pr)^{0.4}$
Fin Tube No. 6	$Nu = 0.018(Re)^{0.8}(Pr)^{0.4}$

Fig. 10. Plain Tube Heat-Transfer Data.

Fig. 11. Plain Tube Heat-Transfer Data.

annuli, dimensional analysis gives the following relationship between the variables:

$$\frac{hD_E}{k} = \left(\frac{D_E V \rho}{\mu}\right)^a \left(\frac{C\mu}{k}\right)^b \left(\frac{D_o}{D_E}\right)^d \left(\frac{D_2}{D_E}\right)^e \left(\frac{S}{D_E}\right)^g \left(\frac{W}{D_E}\right)^j \left(\frac{t}{D_E}\right)^p \quad (14)$$

The individual equations for each tube show that the heat-transfer data may be expressed in the form $Nu = C(Re)^a (Pr)^b$. In the present investigation the quantities D_o, D_2 and t were substantially constant and although the quantities D_o/D_2, D_2/D_E and t/D_E vary somewhat with each tube they are assumed constant and the exponents of S/D_E and W/D_E are determined.

The exponent of S/D_E is determined from the data of Nos. 1 and 2, since all quantities on the right-hand side of Equation (14) are constant except S/D_E. The value of $Nu/Pr^{0.4}$ at constant Re is determined for both tubes and the exponent of S/D_E is determined from the following equation:

$$Nu/Pr^{0.4} = c'(S/D_E)^g \quad (15)$$

From the experimental data at $Re = 10,000$ the value of g was found to be 0.4. Having determined this exponent, values of $Nu/Pr^{0.4}(S/D_E)^{0.4}$ are determined at $Re = 10,000$ and are plotted vs. W/D_E for each tube. The resulting plot gave the exponent of W/D_E as -0.19. All heat-transfer data are then plotted as in Figure 15 as $Nu/Pr^{0.4}$ $(S/D_E)^{0.4}(W/D_E)^{-0.19}$ vs. Re. The line drawn in Figure 15 has the following equation for $Re > 6,000$:

$$Nu = 0.039 \ Re^{0.87} Pr^{0.4}$$

$$(S/D_E)^{0.4}(W/D_E)^{-0.19} \quad (16)$$

The empirical correlation of the data by Equation (16) takes into account the effect of the fin height and fin spacing. The equation agrees well with the experimental data of tubes Nos. 1, 2 and 4 and it is significant to note that all these tubes have similar flow patterns between their fins. Although good agreement is obtained for fin tube No. 3, poor agreement is obtained for tubes Nos. 5 and 6.

The applicability of Equation (16) may be limited to a fin height to fin-spacing ratio of approximately unity. Other ratios or variations in dimensions may cause other mechanisms of turbulence. The heat-transfer coefficients may be expected to vary from Equation (16) much as the coefficients for tubes 5 and 6 vary.

The high coefficients for tube No. 6 can be explained as a result of the turbulence caused by the unstable flow of the fluid at the base of the fins. This unstability which caused high coefficients for fin tube No. 6 was replaced by a "locked" eddy type of flow for fin

tube No. 5, which could be responsible for low heat-transfer coefficients.

Comparison of Performance of Tubes Tested

Experimental data are now available to compare the performance of the one plain and six fin tubes which were investigated. The heat-transfer surface exposed by a fin tube is not all effective, but the efficiency of the surface varies with the heat-transfer coefficient and may be as low as 20 to 30% for high rates of transfer for high fins. The power required to overcome friction on the fin tube is much greater than on the plain tube and the increased amount of heat transfer obtained with fin tubes may cost more or may cost less per unit than with plain tubes.

The performance of the tubes is considered from two aspects. One is the power performance which is the power
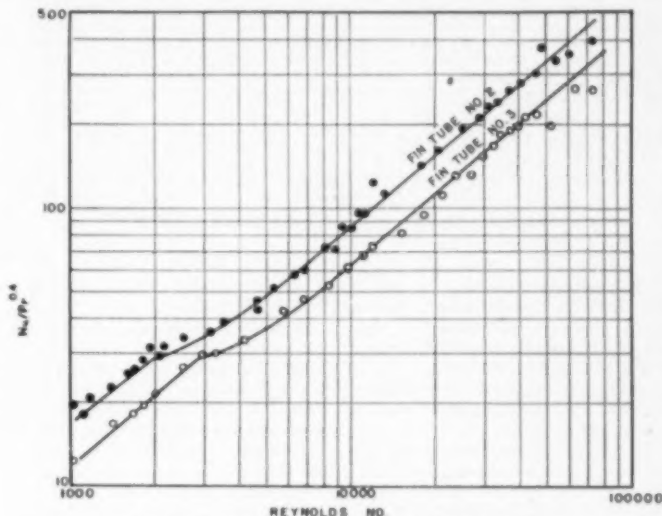
Fig. 12. Heat-Transfer Data for Modified Annuli.
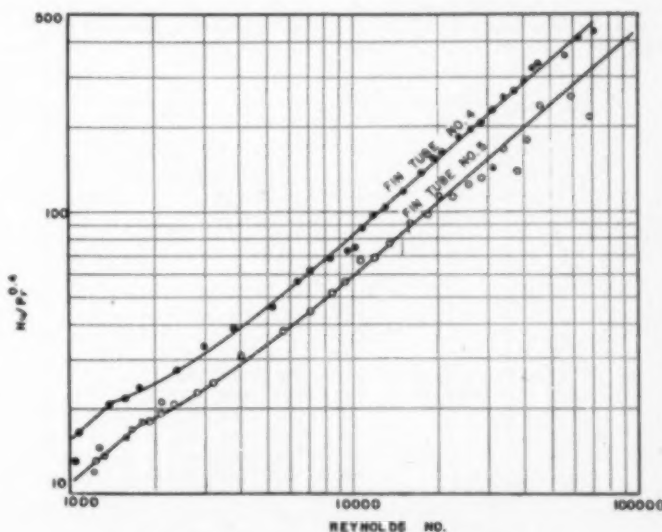
Fig. 13. Heat-Transfer Data for Modified Annuli.

Fig. 14. Heat-Transfer Data for Modified Annuli.

that volume performance is approximately proportional to the outside surface of the tubes. All fin tubes are superior to the plain tube.

Figure 18 is a plot of the heat-transfer coefficients, h_E, as a function of the Reynolds number. In the range of velocities shown, the coefficient on the plain tube is the lowest. The reason for the higher coefficients on the fin tubes is probably the increased turbulence which the fins cause.

Figure 19 (a) and (b) are plots of the over-all heat-transfer coefficients. The broken lines represent U_i as a function of velocity and the solid lines represent U_o. Actually, U_i is the quantity which should be used to compare the heat-transfer capacity of the tubes investigated since U_i is based on the actual inside surface of the tube. All tubes have nearly the same inside surface area. Figure 19 indicates that all fin tubes have greater values of U_i than the plain tube, showing that their heat-transfer capacity is greater.

Acknowledgment

required for the transfer of a unit of heat. The other is the volume performance which is the amount of heat transferred per unit of volume occupied by the exchanger. Both these aspects are important and should be considered together and an economic balance worked between them.

The power performance, volume performance, fin side heat-transfer coefficient and over-all heat-transfer coefficient are calculated and shown in Figures 16-19. The hot stream is always water at 150° F. flowing at 10 ft./sec. inside the tube. The cold stream in the annulus is either water at 60° F. or oil at 100° F. ($\mu = 3.2$ cp., $\rho = 0.84$

g./ml., $k = 0.093$ B.t.u./(hr.)(sq.ft.) (°F.)/(ft.), $Pr = 21$.)

Figure 16 shows the power performance of all the tubes with water and with oil in the annulus. Fin tubes Nos. 1 and 3 both have a better performance than the plain tube in the range of flow rates considered. Fin tube No. 2 is better only at the low values of the Reynolds number. These results indicate that as far as power performance is concerned, there is a certain optimum value of V_f/V_{FF} for which the power performance will be a maximum.

Plots shown in Figure 17 of the volume performance, based on the total volume of the heat exchanger, reveal

Notation

a = constant

A_{EFF} = effective outside area of fin tubes, sq.ft.

A_f = area of finned surface of fin tube, sq.ft.

A_i = inside area of tubes, sq.ft.

A_m = mean area of the tube wall, sq.ft.

A_o = total outside area of tube, sq.ft.

A_p = area of the primary surface of the fin tube, sq.ft.

b = constant

c,c',c'' = constants

C = specific heat, B.t.u./(lb.) (°F.)

d = constant

$\dfrac{dP}{dL}$ = rate of change of pressure with length, lb./cu.ft.

D_1 = outside diameter of fins, ft.

D_2 = inside diameter of outer tube, of annulus, ft.

D_i = inside diameter of inner tube of annulus, ft.

D_E = equivalent diameter of annulus, $D_2 - D_1$, ft.

D_o = root diameter of fin tube, ft.

e = constant

f = Fanning friction factor

f_{2-3} = friction factor over last half of annulus

f_{1-3} = friction factor over whole length of annulus

Fig. 15. Fin Tube Heat-Transfer Data.

LEGEND
○ — FIN TUBE NO. 1
◇ — FIN TUBE NO. 2
◎ — FIN TUBE NO. 3
● — FIN TUBE NO. 4
◆ — FIN TUBE NO. 5
◐ — FIN TUBE NO. 6
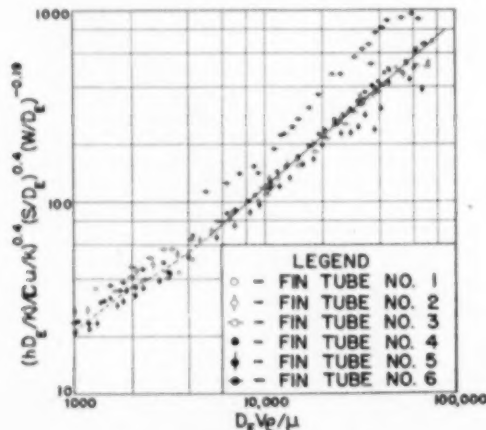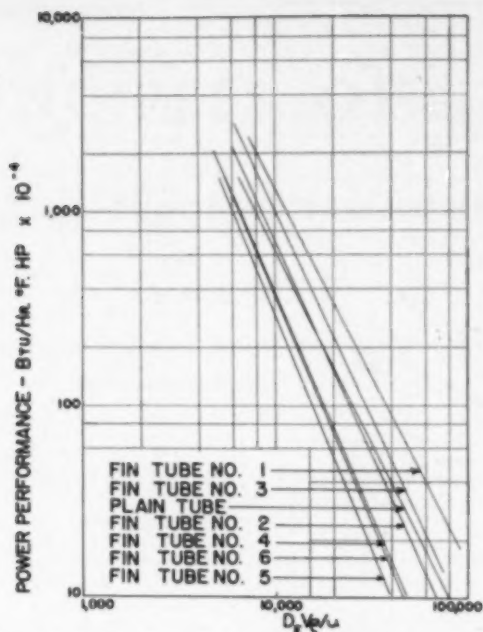
Fig. 16a. Power Performance of Tubes With Water in Annulus at 60° F.

Fig. 16b. Power Performance of Tubes With Oil in Annulus at 100° F.

f_i = isothermal friction factor
f_H = friction factor obtained when fluid in annulus is being heated
g = constant

g_c = dimensional constant, lb. mass (ft.)/(lb. force)(sec.) (sec.)
h = film heat-transfer coefficient in annulus, B.t.u./(hr.) (sq.ft.)(° F.) based on actual outside area of inner tube of annulus

h_E = film heat-transfer coefficient in annulus, B.t.u./(hr.) (sq.ft.)(° F.) based on effective outside area of inner tube of annulus
h_i = film heat-transfer coefficient inside inner tube B.t.u./ (hr.)(hr.)(° F.) based on inside area of inner tube
j = constant
k = thermal conductivity, B.t.u. (hr.)(sq.ft.)(° F.)/ft.
k' = constant
l = wall thickness of inner tube, ft.
m = constant
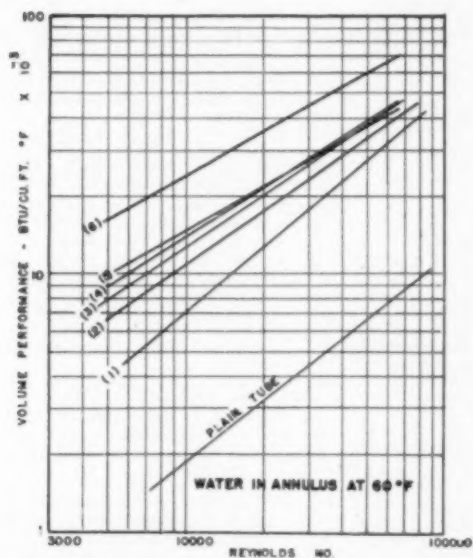
Fig. 17. Volume Performance of Tubes Tested.
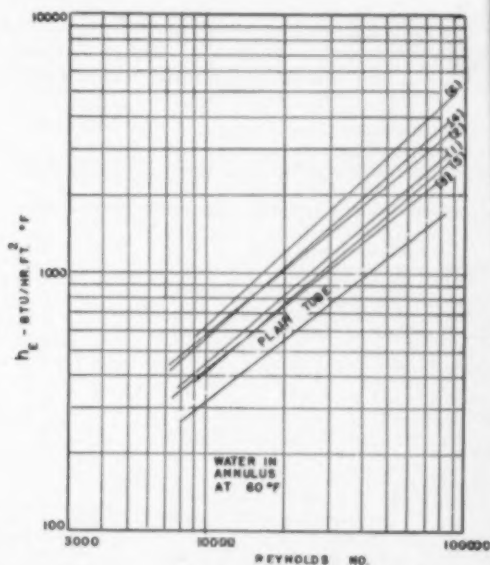
Fig. 18. Annular Heat-Transfer Coefficients for Tubes Tested.
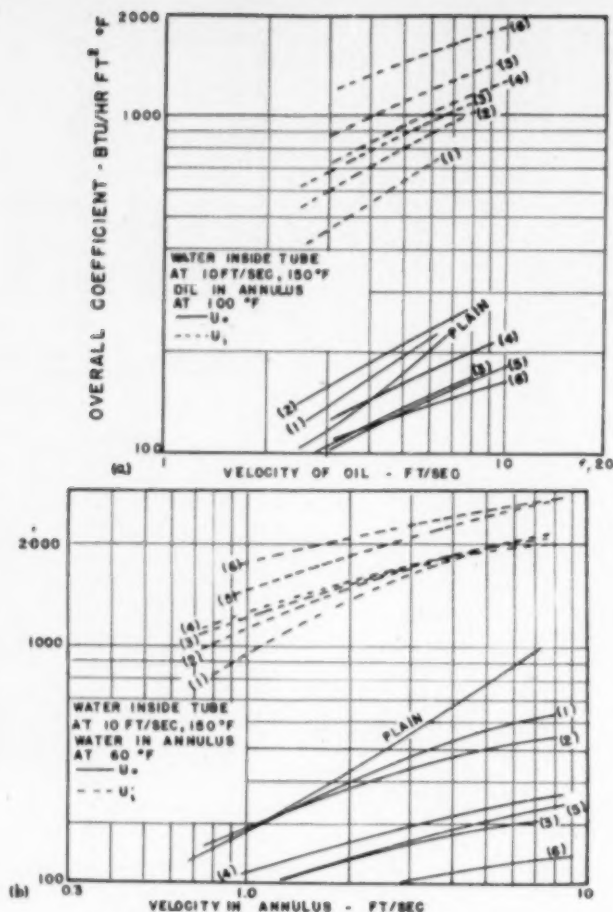
Fig. 19. Over-all Heat-Transfer Coefficients.

n = constant
p = constant
r_h = hydraulic radius of annulus, ft.
S = distance between adjacent fins, ft.
t = thickness of fins, ft.
t' = temperature, °F.
t_b = any arbitrary base temperature, °F.
U_i = over-all heat-transfer coefficient, B.t.u./(hr.) (sq. ft.) (°F.) based on inside area of inner tube
U_o = over-all heat-transfer coefficient, B.t.u./(hr.) (sq. ft.) (°F.) based on outside area of inner tube
V = fluid velocity in annulus based on minimum cross section, ft./sec.
V_f = volume of fin space, cu.ft./ft.
V_{FF} = volume on annular space, cu. ft./ft.

V_i = lineal velocity of fluid inside inner tube, ft./sec.
W = height of fins, ft.

GREEK LETTERS:

α = rate of change of
$$k\left(\frac{\rho}{\mu}\right)^{0.8}\left(\frac{C\mu}{k}\right)^{0.3}$$
with temperature
μ = fluid viscosity, lb./(ft.)(sec.)
μ_w = fluid viscosity at temperature of wall of inner tube, lb./(ft.)(sec.)
ρ = fluid density, lb./cu.ft.
ϕ = fin efficiency
θ_c = temperature correction for Wilson plot

DIMENSIONLESS GROUPS:

Re = Reynolds number $= D_E V \rho / \mu$
Nu = Nusselt number $= h_E D_E / k$
Pr = Prandtl number $= C\mu / k$

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PRINCIPLES OF SPRAY DRYING

PART I—FUNDAMENTALS OF SPRAY-DRYER OPERATION

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SPRAY drying is an operation which has been successfully practiced in special applications since the last quarter of the 19th century. Despite this fact, only in the last 15 years has it begun to find extensive application in the chemical industries. And even today it has not received the fundamental investigation through research that other chemical engineering operations have received.

Several hundred patents on spray drying, issued over the period from 1883 to the present, attest to the constant interest in this subject. Also revealed by these patents are many faulty designs, some of which when reduced to practice failed to operate and gave spray drying an unwarranted bad reputation.

The purpose of this paper is to present a picture of spray drying as it is practiced today, to discuss the principles of spray-dryer operation, and to outline the elements of spray-dryer design and performance.

Spray drying is used to dry pharmaceuticals, fine chemicals, foods, many kinds of trade wastes, organic and inorganic chemicals, rubber latex, and clay slips. In the soap and detergent industries it has become a major operation, and has been developed into a highly specialized art.

Unlike most other drying operations, spray drying requires the designer to consider several equally important operations in addition to drying. These operations usually include mixing and agitation to prepare suitably a liquid feed for atomization, de-aeration of the feed after preparation, pumping of sludges, slurries, and clear liquids of all ranges of viscosity, atomization of simple and complex liquids, the conveying of solids, either pneumatically or mechanically, dust collection by either mechanical or electrical methods, or both, and in some

cases, scrubbing of exhaust gases either to remove fumes or to recover valuable vapors.

Advantages of Spray Drying. The principal advantages are summarized as

1. Certain product properties and quality values may be effectively controlled and varied by spray drying.
    a. Product density can be varied within a given range.
    b. A particle shape approximating a sphere, sometimes hollow, sometimes solid, is usually obtained in spray drying. Generally speaking, such a particle shape is unobtainable by other drying methods. Typical examples of spherical particles of spray-dried commercial products are shown in Figure 6.
    c. The particle size of the product may frequently be controlled or varied in a given range by control of the operating conditions.
    d. Spray drying frequently preserves the quality of a product because drying is so rapid and the material in the hot drying zone is always so wet that it does not become overheated and degraded. Furthermore, the dry product does not become overheated if the gases cool sufficiently from the evaporation process.
2. Spray drying is particularly suited to the atmospheric drying of certain heat-sensitive materials, such as foods, and pharmaceuticals, which otherwise would require high vacuum, low-temperature drying. However, spray drying is not always the answer to drying heat-sensitive materials, especially those which must be dried in the absence of oxygen and/or carbon dioxide.* In certain applications spray

drying has been performed in inert atmospheres in a closed system.

3. Spray drying as it is practiced today may frequently show marked advantages for high tonnage production, since as the output increases, the drying cost per pound of product becomes less than that for other types of dryers. This is generally true when the moisture content of the feed to the spray dryer is not much greater than that of the feed to other types of dryers.

4. A material dried in a spray dryer does not contact solid surfaces until it has become dry. This frequently simplifies corrosion problems and the selection of materials of construction.

5. Spray drying may frequently simplify or eliminate other operations, such as filtration of the feed, and size reduction of the dry product.

6. Since a spray dryer usually operates at temperatures ranging from 400° F. to 1000° F., its efficiency is comparable with that of other types of direct dryers; e.g., rotary dryers, and tunnel dryers.

Disadvantages of Spray Drying. Some disadvantages are inherent in the operation, and others are due to a lack of fundamental knowledge of the operation. The principal ones as spray drying is practiced today are:

1. Low bulk densities are frequently obtained when a high density product is required. This is often the case for inorganic materials which are shipped in carload lots. Although the bulk density of a product from a spray dryer is subject to variation, it sometimes cannot attain the same value as that obtained from other types of dryers without resorting to further processing such as briquetting.

2. In general, spray dryers are relatively inflexible. Thus, a spray dryer designed for fine atomization is generally incapable of producing a coarse product, if such is required.

3. For a given capacity, larger evaporative loads are generally required for spray drying a given material than would be required with other types of dryers. This is due to the requirement

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* It is true, however, that many materials subject to oxidation when dried by other methods may be spray dried; e.g., Bullock and Lightbown (2) showed that ferrous salts were not oxidized when spray dried at a temperature of 500° F. Coulter (4) has shown that dry whole milk, extremely sensitive to oxidation in storage, is no more oxidized when spray dried in air than when spray dried in a nitrogen atmosphere.

Fig. 1. Effect of Air Velocity on Average Drop Size in Two-Fluid Atomization.

Fig. 2. Liquid Flow on Smooth Disk Atomizer.

that the material to be dried must be in a pumpable form for delivery to the atomizer, which usually requires the addition of water. This fact may be one reason for a common misconception that a spray dryer is inefficient. Actually, a spray dryer may be more efficient than other types from a heat utilization standpoint.

4. In general, spray dryers as currently designed involve a higher initial investment than other types of continuous dryers except at high capacities; e.g., above 1500 lb. of product/hr. For this reason, spray drying has not found wide application in the chemical industries to low capacity, continuous drying operations. However, it does compare favorably at low capacities with high vacuum, low-temperature drying operations.

5. Frequently the problems of product recovery and dust collection increase the cost of drying by an appreciable factor, especially when bag filters or scrubbers are required to recover dust exhausted from a cyclone collector system.

Fundamentals of Spray-Dryer Operation

A spray dryer operates on the basis of the creation of a highly dispersed liquid state in a high-temperature gas zone. Consequently, three equally important operations must occur, namely, (1) atomization, (2) drying of liquid drops, and (3) spray-gas mixing. These three operations will be discussed separately.

1. *Atomization.* Atomization is the heart of a spray-drying operation. Its prin-

cipal effect is to produce a high ratio of surface to mass, resulting in high evaporation rates. Its secondary effect is to produce a finely divided product with special physical characteristics of particle shape and density.

Three fundamentally different methods can be used to atomize liquids in spray dryers. These are: (1) pressure atomization by means of pressure nozzles, (2) two-fluid or gas-stream atomization usually with air or steam as the atomizing fluid, and (3) high-speed rotating disks, which atomize by bringing a liquid up to a high velocity by centrifugal force and discharging it into a hot gas zone.

The mechanism of atomization has been studied by many researchers for various purposes. In a pioneering study, Lord Rayliegh (12) investigated the collapse of a liquid jet, at low velocities, when acted on by a disturbance symmetrical to the axis of the jet. Based on the assumption of streamline flow in the jet, he found that a symmetrical disturbance will cause the break-up of a jet or ligament when the amplitude of the disturbance grows to one-half the diameter of the undisturbed jet or column of the liquid. Other theories of the mechanism of atomization have been postulated (3, 8, 24, 25) which introduce air friction and turbulence. However, this subject is still highly controversial and requires much research for clarification.
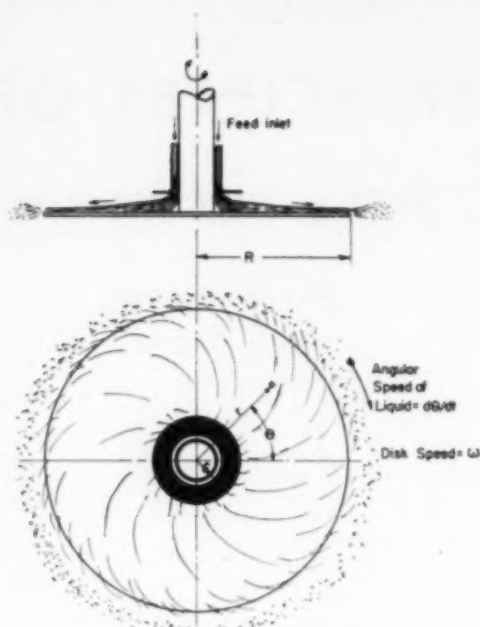
Pressure Atomization. Studies (8, 11, 16) of the disintegration of jets from pressure nozzles have led to the following conclusions which summarize the present theories on the mechanism of atomization by this method:

1. If the liquid jet is turbulent throughout, it will disperse without the application of any external force; e.g., disintegration will occur in a vacuum. This is because in a liquid stream in turbulent flow the liquid particles have definite radial velocity components so that when the jet is no longer confined by the orifice walls the particles are restrained only by the surface tension force of the liquid. Disintegration of the jet occurs as the surface tension is overcome. Thus, it may be concluded that at high pressures, surface tension is a controlling factor in atomization. This conclusion was reached from experiments by Kuehn (11).
2. If the jet is in semiturbulent flow, i.e., with a laminar layer surrounding a turbulent core, then disintegration of the jet will occur after leaving the nozzle when the turbulent core forges ahead of the laminar layer.
3. If the jet is in laminar flow, air friction or some other external disturbance is essential to its disintegration. This leads to the conclusion that at low nozzle pressures viscosity will be a controlling factor. It also suggests the possibility that a jet in laminar flow will not atomize in a vacuum.
4. Regardless of the type of flow, disintegration or atomization is believed to be favored by air friction (16).
5. The higher the viscosity of the liquid, the longer the break-up distance of the jet.

6. As the pressure increases, the break-up distance decreases.
7. The break-up of a jet is influenced by roughness of the orifice and other factors affecting the general turbulence conditions of the liquid as well as the smoothness of the liquid surface.

In spite of the extensive studies of atomization by pressure nozzles, published data on drop-size distribution from such nozzles are meager. These data are essential for the development of any rational analysis of the role of atomization in spray drying and related operations.

Of the above conclusions, probably the only ones of real concern in spray drying are those dealing with turbulent jets. It would be unlikely to encounter jets in viscous flow in spray drying. Further, no correlation is presented between these conclusions and the operation of commercial nozzles. However, it is not unreasonable to believe that these conclusions can be applied to various designs of pressure nozzles.

Two-Fluid Atomization. The atomization of liquids by high velocity gas streams has been studied by Castleman (*3*), Littaye (*18*), Sauter (*24*), Schuebel (*25*), Nukiyama and Tanasawa (*20*), Lewis et al (*17*), and others. In postulating a mechanism for this method of atomization, Castleman assumed that (1) it is a necessary step first to form ligaments from the large mass of liquid, and (2) the rate of collapse of these ligaments follows Rayleigh's theory for the collapse of a liquid column. Spark photographs by Lee (*16*) showed that such ligaments actually are torn by air friction from the main body of the liquid. Studies by Sauter, Nukiyama and Tanasawa, Littaye, and Lewis et al showed that as the air velocity is increased finer atomization is obtained resulting from finer ligaments being torn from the liquid at higher air velocities.

Nukiyama and Tanasawa presented the following empirical equation for predicting a surface average drop size for atomization by high velocity gas streams:

$$D_o = \frac{585\sqrt{\sigma}}{v\sqrt{\rho}} + 597\left(\frac{\mu}{\sqrt{\sigma\rho}}\right)^{0.45}\left(\frac{1000 Q_L}{Q_o}\right)^{1.5} \quad (1)$$

Equation (1) has been plotted in Figure 1 for water at 20° C. It can be seen that the effect of the term involving viscosity, becomes negligible when the ratio of the volumetric rates of liquid and gas becomes less than 10^{-4}. This is not inconsistent with the conclusions regarding the diminishing effect of viscosity as the pressure increases in pressure nozzle atomization. These investigators also suggested that the distribution of particle size obtained by atomiza-

tion with high velocity gas streams might be expressed by the relationship:

$$\frac{dn}{dx} = a x^p e^{-mx^j} \quad (2)$$

where j is a function of the nozzle design. Equation (2) is general, since with four empirical constants it can be made to conform to almost any type of curve. Nukiyama and Tanasawa found that for the nozzles studied p was nearly always 2, and that when $Q_L/Q_o < 10^{-4}$, (cf. Fig. 1), $j = 1$ for two-fluid nozzles.

Lewis et al investigated the applicability of Equation (2) to pressure atomization as well as to atomization by means of high velocity gas streams, and attempted to establish values of the empirical constants for the conditions studied.

Rotating Disk Atomization. The literature contains little information on the characteristics of rotating-disk atomizers, even though this type has found widespread application in spray drying. Bar (*1*) made a study of two types of rotating atomizers. One consisted of radial tubes through which liquid was

forced to flow by centrifugal force and atomize as it was ejected from the end of the rotating tubes. He called this type a velocity sprayer. The second type studied was a smooth disk which he designated as a centrifugal sprayer. Wilson, Page, and Cartwright (*29*) reported an extensive spray-drying study of various types of spray disks in the spray drying of clay slip. Hinze and Milborn (*8b*) studied the atomization of liquids by rotating cups, and confined their investigation to the viscous flow region. Hickman (*8a*) studied the characteristics of liquid flow on a rotating disk in connection with molecular distillation.

Operation of rotating-disk atomizers consists of centrifugally accelerating a liquid to a high velocity before discharging it into a gas atmosphere. This method differs from the pressure nozzle in that the liquid attains its velocity without being subjected to high pressures, frequently with a free liquid surface exposed to a gas phase during passage over the disk. In some designs, the liquid is forced through radial tubes.

Several types of rotating disks may be used to atomize liquids. The simplest, of course, is a flat, smooth disk near the center of which the liquid is deposited. If no slippage occurs between the liquid and the disk, and if no frictional force retards the flow, the time required for the liquid to reach the disk periphery
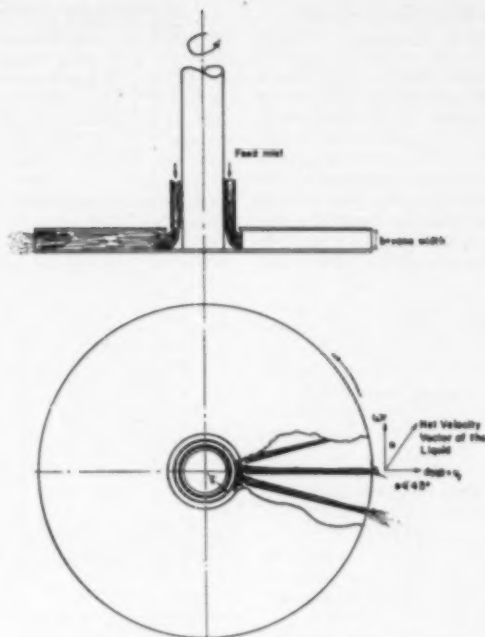
Fig. 3. Liquid Flow on a Vaned Disk.

would be given by the relationship:

$$N_\theta = \text{arc cosh } (r/r_o) \quad (3)$$

where N_θ = the number of radians a liquid particle passes through before reaching the edge of the disk. $N_\theta = 2\pi N t$, where N = rate of rotation, t = time. Equation (3) is an idealization difficult to realize. A more general case (Fig. 2) which considers both slippage and frictional resistance in laminar flow leads to the following set of simultaneous, nonlinear, ordinary differential equations:[*]

$$\frac{d^2r}{dt^2} + \left(\frac{2\pi\mu\phi}{q\rho_L}\right)r\left(\frac{dr}{dt}\right)^2 - r\left(\frac{d\theta}{dt}\right)^2 = 0 \quad (4)$$

$$\frac{d}{dt}\left(r\frac{d\theta}{dt}\right) - \frac{2\pi\mu\phi}{q\rho_L}r^2\left[\omega - \frac{d\theta}{dt}\right]\frac{dr}{dt} = 0 \quad (5)$$

Where ω is the disk rotational speed, and $d\theta/dt$ is the liquid rotational speed. This system can be solved only by approximation or machine methods. When no slippage occurs, Equation (5) is eliminated, and with the added assumption of no friction the second term of Equation (4) is removed.

A second method may be visualized involving a disk having a number of equally spaced radial vanes to prevent slippage of the liquid over the disk surface, thereby effectively eliminating Equation (5). In this case, the liquid may be pictured (Fig. 3), as riding on the vanes perpendicular to the plane of the disk. If the force of gravity is neglected and it is assumed that the flow of liquid is retarded by a viscous resistance expressed by the relationship $\tau = \phi\mu(dr/dt)_{ave}$, the following differential equation relating the time and radial position of a liquid particle may be written:

$$\frac{d^2r}{dt^2} + a\left(\frac{dr}{dt}\right)^2 - \beta r = 0 \quad (6)$$

where

- r = radial distance from the center of the disk
- t = time for particle to move radially from r_o, point of deposit on disk, to r
- $a = \dfrac{\phi\mu b}{q\rho_L}$
- μ = viscosity
- b = vane height
- q = volumetric rate of liquid flow per vane
- ρ_L = liquid density
- ϕ = a factor depending on the depth of liquid on the vane and as used in Equation (6), an average value must be taken

[*] These equations were developed by one of the authors in collaboration with R. L. Pigford of the University of Delaware.
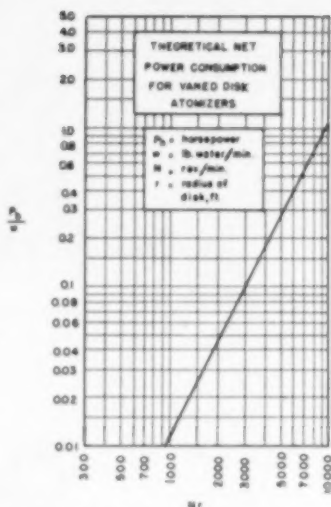
Fig. 4. Effect of Feed Rate, Disk Speed, and Disk Size on Power Consumption of Disk Atomizers.

$$\beta = \omega^2$$

ω = angular velocity of disk

Equation (6) is of the same form as Equation (4) when no slippage occurs. The integral for Equation (6) for the time of passage of liquid in viscous flow on a vaned disk may be written as

$$N_\theta = \frac{1}{\sqrt{2}}\int_{\xi_o}^{\xi}[\xi - \xi_o e^{(\xi_o - \xi)}]^{-\frac{1}{2}}d\xi \quad (7)$$

where

- N_θ = dimensionless time = ωt
- $\xi = (2ar - 1)$
- $\xi_o = (2ar_o - 1)$

In order to evaluate Equation (7), the value of a, and r_o, the point where liquid is deposited on the disk, must be specified. The range of ar can be so great as to preclude the feasibility of calculating a set of curves to cover all possible conditions of liquid flow and viscosity. Equation (7) should be interpreted as an approximation to the case of laminar flow on a vaned disk and possibly as a guide to interpreting experimental studies. Possibly a more useful relationship to be derived from Equation (6) is the expression for radial velocity at any distance r. This may be written as

$$v_r = \frac{\omega}{a\sqrt{2}}\sqrt{2ar - 1 - Ce^{-2ar}} \quad (7a)$$

From the volumetric flow rate per vane, the average thickness of the film leaving the vane can be estimated by the relationship:

$$y = \frac{q}{v_r b}$$

$$= \frac{qa\sqrt{2}}{b\omega}(2ar - 1 - Ce^{-2ar})^{-\frac{1}{2}} \quad (7b)$$

It remains for experimental studies to show whether or not the average drop size from a vaned disk can be correlated with y as estimated from Equation (7b).

Inasmuch as the value of ϕ used in the expression for frictional resistance is a function of the liquid depth y, a more rigorous equation to include this variation may be written as follows:

$$\frac{d^2r}{dt^2} + a'\left(\frac{dr}{dt}\right)^3 - \beta r = 0 \quad (6a)$$

where now

$$a' = \frac{3\mu b^2}{q^2\rho_L}$$

and the constant 3 arises from the assumption of a parabolic velocity distribution in the liquid film on the vane. Equations (4) and (5) may be similarly modified.

An approximate solution for dr/dt from Equation (6a) is possible on the assumption that the ratio of radial velocity to peripheral velocity is constant in the range of disk sizes usually encountered. Thus a solution for dr/dt is obtained as follows:

$$\frac{dr}{dt} = v_r = \sqrt{\frac{\omega}{a'\delta}}\tanh\sqrt{\frac{\omega a'}{\delta}}(r - r_o) \quad (7c)$$

where δ = the ratio $v_r/\omega r$ = constant. This assumption appears to be acceptable as long as the value of the hyperbolic tangent does not exceed about 0.8, or $\sqrt{\omega a'/\delta}(r - r_o) < 1.2$. Further, Equations (6a) and (7c) are valid only for the case of laminar flow. If turbulent flow is considered, an expression similar to Equation (6a) is obtained as follows:

$$\frac{d^2r}{dt^2} + \frac{fb}{2q}\left(\frac{dr}{dt}\right)^3 - \omega^2 r = 0 \quad (7d)$$

where $f/2$ is the usual friction factor for turbulent flow. If the above assumption is made regarding the constancy of the ratio of the radial and peripheral velocity components, then an approximate relation for v_r for turbulent flow may be obtained analogous to Equation (7c) as follows:

$$v_r = \sqrt{\frac{2\omega q}{fb\delta}}\tanh\sqrt{\frac{\omega fb}{2q\delta}}(r - r_o) \quad (7e)$$

If a' or f approaches zero, then the limit of Equations (7c) and (7e) becomes $\omega(r - r_o)$.

A spinning disk imparts two velocity components to the liquid, one peripheral and the other radial. Thus, the net ve-

locity vector of the liquid may be written as (cf. Fig. 3)

$$v = \sqrt{v_g{}^2 + v_r{}^2}$$
$$= \sqrt{(\omega r)^2 + v_r{}^2} \qquad (8)$$

while the angle of this resultant velocity is

$$\theta = \tan^{-1}\frac{v_r}{v_g} \leqslant 45° \qquad (8a)$$

This angle approaches 45° as a limit when the viscosity or frictional resistance is small, or when the flow rate is large. From this consideration and Equation (8) the maximum kinetic energy E_{max}, that can be delivered to the liquid leaving a centrifugal disk can be written as

$$E_{max} = \tfrac{1}{2}mv^2 = \tfrac{1}{2}m(2(\omega r)^2)$$
$$= m(\omega r)^2 \qquad (8b)$$

From this, an expression for net power may be written as follows:

$$P' = \frac{w'}{g_c}(\omega r)^2 \qquad (8c)$$

where

P' = power, (ft.)(lb.)/(sec.)
w' = lb. of liquid/sec.
ω = angular velocity, radians/sec.
r = outer radius of the disk, ft.
g_c = conversion factor, (lb.)(ft.)/ (sec.)²(lb.force)

Equation (8c) may be written in terms of horsepower and revolutions per minute as follows:

$$P_h = 1.02 \times 10^{-8}w(Nr)^2 \qquad (9)$$

where

P_h = net horsepower
w = lb. of liquid/min.
N = rev./min.
r = disk radius, ft.

Equation (9) has been plotted in Figure 4. For disks on which liquid slippage is likely to occur, the net power will lie below the curve for Equation (9). Total power is obtained by correcting the net power for various transmission and motor efficiencies. If a disk pumps large quantities of air, in addition to accelerating the liquid, the net power may be greater than that predicted by Equation (9).

It is interesting to note that the power required to create new surface, based on thermodynamic considerations, is only a small fraction of that actually expended in a conventional atomizer. Thus, to create new surface, the theoretical power required is

$$P = A\sigma \qquad (10)$$

where

A = net average area created/min.
σ = surface tension, lb.force/ft.
P = power required to create new surface, ft.-lb./min.

If a gallon of water per minute is atomized to a spray with a surface average drop size of 50μ, this would be equivalent to creating 4900 sq.ft. of new surface/min. The power required according to Equation (10) is 25 (ft.) (lb.)/min., or 0.00076 hp. If the power were figured from Equation (8c) for a 6-in. disk atomizer giving the same degree of atomization at 15,000 rev./min., 160,000 (ft.)(lb.)/min. would be required, or about 5 hp. Thus, the theoretical power for atomization is only 0.02% of that which might actually be expended by a disk atomizer. If a pressure nozzle atomizing 1 gal./min. at 4000 lb./sq.in. can produce the same average drop size, the power consumption will be about 80,000 (ft.)(lb.)/min., half that of the disk, but still many hundred fold greater than the theoretical minimum power required. A similar estimate for a two-fluid nozzle indicates a power requirement on the order of 200,000 (ft.)(lb.)/min. It is evident that atomization is a process accompanied by a large increase in entropy. This large difference between actual and theoretical power suggests the need of research to develop new methods of atomization, which will consume much less energy per unit of surface created. It is to be recognized, however, that much of the energy consumed in atomization must go into dispersing the drops and mixing them with their surroundings. Certainly this is an important part of the atomization process in spray drying.

The particle trajectories of the various atomizers are a function of the type and design. In general, the spray pattern from nozzles tends to be conical in shape, the included angle of the cone seldom exceeding 120°. The spray pattern of disks, however, resembles more nearly an umbrella, with the particle trajectories usually in the plane of the disk. Certain disk designs, however, may eject a spray at an angle to the plane of the disk. The various trajectories and spray patterns of atomizers materially influence the design of a spray dryer, and the configuration of the drying chamber.

One controversial question concerning the various types of atomizers is: Which type will produce the most uniform drop-size distribution for given conditions? However, this has never been answered by comparative studies of each type. It is believed that with proper design and operation a pressure nozzle and a rotating disk can be made to produce sprays with approximately the same particle size distribution, even though each type may not produce a particle-size distribution following the same mathematical law. A comparative study of each atomizer under comparable conditions involves the tedious problem

of sampling the spray and counting the drops in various size ranges. Several thousand drops must be counted in each sample for satisfactory accuracy. This laborious procedure has represented a tremendous obstacle to atomization research, but with the development of automatic drop counters of the type described by Rupe (23), it is anticipated that considerable progress will be made on comparative studies of the various types of atomizers. It is well to point out that there may be a considerable difference between the drop size created at the atomizer and the finished product particle size. Puffing of the drop and agglomeration contribute to effect the change in original drop size.

It is proposed that a comparison of atomizers should involve the following fundamental aspects:

1. Nozzle capacity expressed as square feet of surface created per pound of liquid atomized per minute
2. Efficiency expressed as power consumed per square foot of surface created
3. Drop-size distribution or sharpness index for identical flow rates
4. Weight flow distribution

A further comparison of nozzles and disks reveals the latter to be somewhat more flexible from the standpoint of variations in operating conditions. Thus, for a given problem a disk might handle a variation of feed rate in a range of ±25% of design capacity without greatly affecting the particle size of the product and without the necessity of changing operating conditions, provided excess power is available. In order to handle an increased capacity with nozzles, either the pressure must be raised, or if constant pressure is desired larger nozzles must be substituted. Nozzles on the other hand are more adaptable to countercurrent flow operation because of the more confined nature of their spray pattern. Adaptation of a disk to counterflow operation involves methods for bending the spray trajectories either by air flow or disk design, or both. Rather high air velocities are required to disturb appreciably the trajectory of the spray of liquid near the spinning disk.

In general, both nozzles and disks will handle fluids of the same consistency. Disks may frequently handle heavy sludges which cannot be satisfactorily pumped with piston pumps and atomized by pressure nozzles. On the other hand, pressure nozzles have been found well suited, for example, for atomizing a viscous liquid which tends to form strings on disks, by superheating the liquid under pressure so that on ejection from the nozzle an added disrupting force due to sudden vapor formation aids atomization.

2. Drying of Drops.

2. *Drying of Drops.* The second important phase of spray drying concerns the drying rate of drops. Considerable attention has been given to the evaporation of pure liquid drops. An extensive experimental study of the evaporation of spherical drops of aniline, naphthalene, nitrobenzene, and water was reported by Froessling (6). Sherwood and Williams (28) correlated much of the significant published data on mass transfer from liquid drops, and on heat transfer to solid spherical particles. Their recommended equations for mass transfer for three different ranges of Reynolds number may be written as follows:

I   For $N_{Re} < 4.0$

$$N'_{Nu} = \frac{k_g R T D_p}{D} = 2.0 \quad (11)$$

II   For $4 < N_{Re} < 400$

$$N'_{Nu} = 1.5 (N_{Sc})^{\frac{1}{3}} (N_{Re})^{0.39} \quad (12)$$

III   For $N_{Re} > 400$

$$N'_{Nu} = 0.43 (N_{Sc})^{\frac{1}{3}} (N_{Re})^{0.56} \quad (13)$$

Froessling presented the following equation for all values of N_{Re}:

$$N'_{Nu} = \frac{k_g R T D_p}{D}$$
$$= 2[1 + 0.276 (N_{Sc})^{\frac{1}{3}} (N_{Re})^{0.5}] \quad (14)$$

The corresponding equation for heat transfer is:

$$N_{Nu} = \frac{h D_p}{k_f}$$
$$= 2[1 + 0.276 (N_{Pr})^{\frac{1}{3}} (N_{Re})^{\frac{1}{2}}] \quad (14a)$$

It is evident that Equations (11) and (14) are equivalent at low values of N_{Re}.

Evaporation Lifetime of Pure Liquid Drops. Since the rate of evaporation of a pure liquid drop is proportional to the rate of heat transfer to its surface, a heat balance gives

$$-\rho_L \frac{d}{d\theta}\left(\frac{\pi D_p^3}{6}\right) = \frac{h \pi D_p^2 \Delta t_m}{\lambda} \quad (15)$$

which reduces to

$$\frac{2 \Delta t_m}{\rho_L \lambda} d\theta = -\frac{d D_p}{h} \quad (15a)$$

If $2\Delta t_m / \rho_L \lambda$ is effectively constant, a condition which is often met under actual drying operations, integration of Equation (15) gives the lifetime of a drop. Thus,

$$\theta = \frac{\rho_L \lambda}{2\Delta t_m} \int_0^{D_{p1}} \frac{dD_p}{h} \quad (16)$$
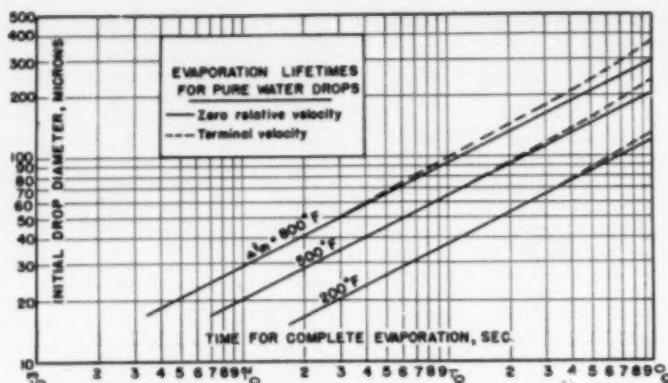
The integration indicated by Equation (16) requires data on the film coefficient h at various values of D_p.

Equation (16) may be generalized further by substituting for h its value as given by Equation (14a). This substitution gives the following more general expression for the evaporation lifetime of a pure liquid drop:

$$\theta = \frac{\rho_L \lambda}{4\Delta t_m k_f} \int_0^{D_{p1}} \frac{D_p dD_p}{\left[1 + 0.276\left(\frac{f\mu}{k_f}\right)^{\frac{1}{3}}\left(\frac{D_p v \rho}{\mu}\right)^{\frac{1}{2}}\right]} \quad (17)$$

Equation (17) is useful only if a relationship between D_p and the velocity, v, in the Reynolds number is known.

Case of Zero Relative Velocity; i.e., $v = 0$. In spray drying it is not unusual for N_{Re} to be low; i.e., for a low relative velocity to exist between the particle and the gas, or for small drops to be involved. Even at high velocities, a low Reynolds number occurs with small particles. Equation (14a) for zero relative

velocity simplifies to the following expression for h:

$$h = \frac{2k_f}{D_p} \quad (18)$$

When this expression for h is substituted in Equation (16), or when $v = 0$ in Equation (17), the time for complete evaporation is given by

$$\theta = \frac{\lambda \rho_L D_{p1}^2}{8 k_f \Delta t_m} \quad (19)$$

Thus the lifetime of a drop for zero relative velocity is found to be propor-

tional to the square of its initial diameter and inversely proportional to Δt_m and the gas film thermal conductivity, k_f.

Lifetime of a Drop Falling at Terminal Velocity. If v in Equation (17) equals v_t, the terminal velocity, the lifetime can be obtained using values of v_t

calculated by the method of Lapple and Shepherd (13). Such a calculation, however, is generally quite laborious.

If the drop is falling at terminal velocity in Stokes' law or streamline flow region, a comparatively simple relationship between v_t and D_p exists as follows:

$$v_t = \frac{g(\rho_L - \rho_a)D_p^2}{18\mu} \quad (20)$$

and Equation (17) becomes

$$\theta = \frac{\rho_L \lambda D_{p1}^2}{8\Delta t_m k_f}\left[1 - \frac{2}{D_{p1}^2} \int_0^{D_{p1}} \frac{B D_p^{5/2} dD_p}{(1 + B D_p^{3/2})}\right] \quad (21)$$

where

$$B = 0.276\left(\frac{c\mu}{k_f}\right)^{\frac{1}{3}}\left[\frac{g(\rho_L - \rho_a)\rho_a}{18\mu^2}\right]^{\frac{1}{2}} \quad (21a)$$

The value of B for air will vary from approximately 240 at 400° K. to 81 at 1000° K. Thus the evaporation lifetime of a drop falling throughout at terminal velocity in the Stokes' law region is less than its lifetime when evaporating in still air by a fraction equal to

$$\frac{2}{D_{p1}^2} \int_0^{D_{p1}} \frac{B D_p^{5/2} dD_p}{(1 + B D_p^{3/2})}$$

Fig. 5. Effect of Drop Diameter on Time for Complete Evaporation of Water Drops.

Equation (21) may be integrated in a series form to give the following result:

$$\theta = \frac{\rho_L \lambda D_{p1}^2}{8 \Delta t_m k_f} \left[1 - \sum_{m=1}^{n} (-1)^{m-1} \frac{4}{3m+4} B^m D_{p1}^{3m} \right] \qquad (22)$$

The series converges if

$$D_{p1}^{3/2} < 1/B$$

In Figure 5, Equations (19) and (22) have been plotted for various values of Δt_m to compare the evaporation time for zero relative velocity with the lifetime of the drop if it is moving throughout at its terminal velocity in the Stokes' law region. It is evident from this plot that the effect of a velocity equal to the Stokes' law terminal velocity is negligible until initial drop diameters on the order of 300µ are involved.

The Reynolds number range of greatest significance in spray-drying applications is 10^{-1} to 10^2. The Stokes' law region is generally accepted to be in the range $N_{Re} < 2.0$. Particles of 50µ and less subjected to relative velocities 300 to 500 ft./sec. will not exceed a Reynolds number of 200. However, the time during which such relative velocities exist is short, since the particles will be rapidly speeded up or slowed down to the air velocity. Consequently, it would be expected that a spray particle in a spray dryer will be, for the most part, in the Stokes' law region of flow. Consequently, Figure 5 should give a reasonably close approximation to the time required for complete evaporation of pure liquid drops of the size usually encountered in spray drying.

The foregoing consideration of the evaporation of liquid drops assumes that no foreign matter exists in the liquid. Hence the correlations and equations presented represent only approximations to the actual case in spray drying where a solid exists in the drop, either in suspension or in solution. When a solid is present in the drop all the usual complications of any drying problem are encountered. Thus, a period of free water evaporation will occur followed by a period when the solid phase offers the principal resistance to evaporation. Also encountered is the problem of case-hardening when the drop surface forms a dry skin during the first instant of drying. In such a case, the entrapped liquid may exert a pressure as it vaporizes, and will either stretch or rupture the case-hardened surface of the drop. This results in a hollow-sphere type of particle with or without blow-holes in the sphere wall. Spray-dried soap beads are the most typical examples of this phenomenon. However, hollow particles may be obtained with composed of agglomerates of original submicron particles of the solid. Such a structure is usually easily disintegrated to the ultimate particle size if there is no cementitious material holding the particles together. A particle of this type might be obtained with dyes, paint pigments, insecticides, inorganic salts, and similar materials which have been very finely divided prior to drying, and washed free of impurities.

Few experimental studies on the drying of liquid drops containing a
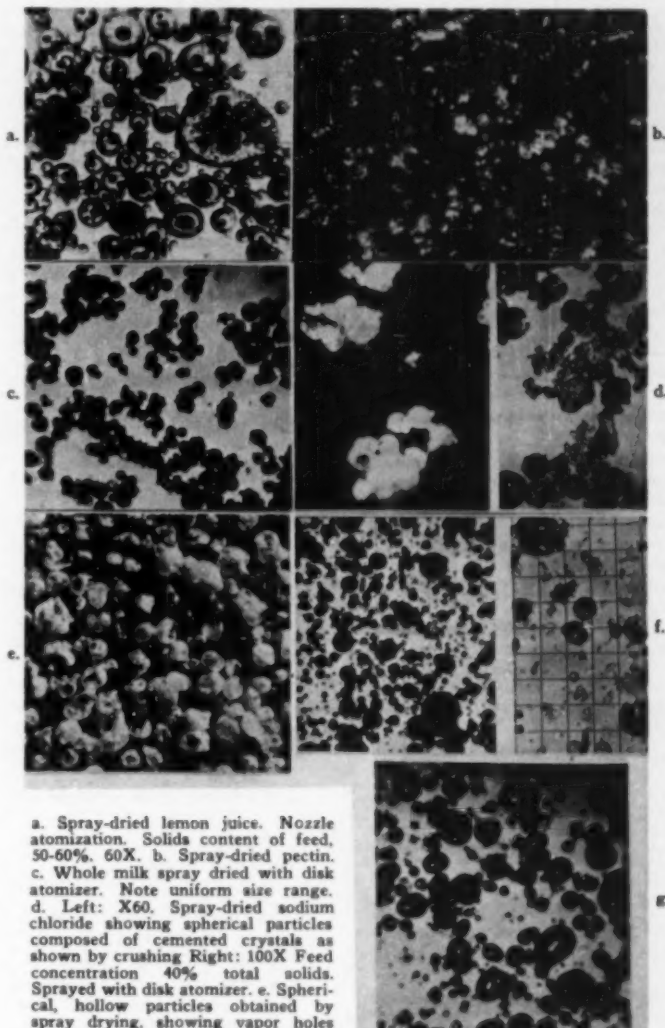
a. Spray-dried lemon juice. Nozzle atomization. Solids content of feed, 50-60%. 60X. b. Spray-dried pectin. c. Whole milk spray dried with disk atomizer. Note uniform size range. d. Left: X60. Spray-dried sodium chloride showing spherical particles composed of cemented crystals as shown by crushing Right: 100X Feed concentration 40% total solids. Sprayed with disk atomizer. e. Spherical, hollow particles obtained by spray drying, showing vapor holes through the shell. 24X. f. Left: X60 Spray-dried coffee showing wide size range. Right: X200 Transparent shells of fractured particles typical of low density powders. g. Spray-dried gelatin showing elongated, egg-shaped particles, typical of two-fluid atomization of viscous solutions. 80X.

Fig. 6.

solid have been reported (22, 30). Hence, it is difficult to predict how accurately the drying times estimated from Figure 5 for pure liquid drops will apply to drops with a solid present. Presumably it is a fair approximation for materials forming porous particles, and for drops with a low solid content and no tendency to case-harden. It would not be expected to hold for materials such as soap, nor for salt solutions which produce heat effects due to crystallization, and which appreciably reduce the normal vapor pressure of water with increased concentration.

3. *Spray-Gas Mixing.* The third important step in the spray-drying process is effective mixing of the spray and gas. It is evident from the short drying times involved in spray drying that the time required to effect intimate mixing of the spray and gas may be appreciably longer than the drying itself. Herein lies the possibility for the greatest single improvement in spray-dryer design.

The various spray dryer designs today reflect in large measure the various attempts that have been made to solve this spray-gas mixing problem. The flow of gas and spray may be cocurrent, countercurrent, or a combination of both. The spray may be directed vertically down or up, horizontally, or at an angle to the vertical. Spray dryers embodying all of these features are in existence.

A factor greatly influencing this problem of mixing is the trajectory pattern of the various atomizing devices. Thus, the problem of effecting intimate mixing of a spray coming off at all points around a rotating disk may be more difficult than mixing the conical-shaped spray from a pressure nozzle.

The principal schemes of air flow and spray-gas mixing found in spray dryers as designed today will be indicated in Part II of this paper which will consider the elements of spray-dryer design.

Notation

a = empirical constant in distribution equation, Equation (2)

A = area; net surface area, Equation (10)

b = height of vane on vaned disk, Equations (6) and (7b)

B = constant defined by Equation (21a)

c_p = specific heat at constant pressure

$C = (2ar_o - 1)e^{2ar_o}$, Equation (7a)

D = diffusion constant

D_o = specific surface average particle size, Equation (1)

D_p = particle diameter

$f/2$ = friction factor

G = mass velocity

g = acceleration due to gravity

g_c = conversion factor, (lb. mass) (ft.)(lb. force)(sec.)^2

h = film coefficient for heat transfer, B.t.u./(hr.)(sq. ft.)(°F.)

j = empirical constant, Equation (2)

k_g = film coefficient for mass transfer, lb.-mole/(hr.)(sq. ft.)(atm.)

k_f = thermal conductivity of gas film

m = empirical constant, Equation (2)

m = mass, Equation (8b)

M = molecular weight

N = rate of rotation

N_{Nu} = Nusselt number = hD_p/k_f

$N_{N'u}$ = Nusselt number corresponding to mass transfer = $k_g RTD_p/D$

N_{Sc} = Schmidt number = $(\mu/\rho D)$

N_{Re} = Reynolds number = $(D_p v \rho/\mu)$

N_{Pr} = Prandtl number = $(c_p \mu/k)$

N_θ = dimensionless time of retention on disk atomizers = ωt

n = number of particles of size x, Equation (2)

P = power, (ft.)(lb.)/min.; $P' $ = (ft.)(lb.)/sec.

P_h = horsepower

p = empirical constant, Equation (2)

Δp_m = mean partial pressure difference

q = volumetric liquid flow rate, vol./(unit time)(vane), Equation (6)

Q_a = volumetric rate of air flow, Equation (1)

Q_L = volumetric rate of liquid flow, Equation (1)

R = gas constant

r = radial distance

r_o = radial distance on disk where liquid is deposited

T = absolute temperature

t = time of passage on disk

t_1, t_2 = inlet and outlet gas temperature, respectively

t_o, t_w = atmospheric temperature and wet-bulb temperature, respectively

t_s = adiabatic saturation temperature

Δt_m = mean temperature difference between drop and surrounding air

V = gas velocity

v = relative velocity between gas and liquid; m./sec., Equation (1); consistent units Equation (7)

v_θ = peripheral velocity = ωr

v_r = radial velocity on vaned disk, Equation (7a)

v_t = terminal velocity of falling drop

w = flow rate, lb./min.

w' = lb./sec.

W = moisture content, lb. moisture/lb. dry solid

x = particle size in distribution equation, Equation (2)

y = thickness of liquid at any distance r on a vaned disk atomizer, Equation (7b)

GREEK:

$\alpha = \phi \mu b/q\rho_L$, (length)$^{-1}$, Equation (6)

$\alpha' = 3\mu b^2/q^2 \rho_L$, (time)/(length)^2, Equation (6a)

$\beta = \omega^2$, Equation (6)

$\delta = v_r/\omega r$

η_o = over-all dryer efficiency

η_e = evaporative efficiency

θ = angle, radians, Equations (4) and (5)

θ = evaporation time of liquid drops, Equations (16)-(18)

λ = latent heat of evaporation

μ = viscosity; poises, Equation (1)

ξ = dimensionless radial distance = $(2ar - 1)$, Equation (7)

ρ = liquid density, g./cc. in Equation (1)

ρ_a = air density, Equation (20)

ρ_L = density of liquid

ρ_s = density of solid

σ = surface tension; dynes/cm., Eq. (1); lb./ft., Equation (10)

ϕ = factor involved in frictional resistance in liquid flow on disk atomizer, Equations (4)-(6)

τ = tractive force, force/unit area

ω = angular velocity, radians/unit time

(Literature Cited and Discussion will be published with Part II in the November issue.)

APPLICATION OF ION EXCHANGE

Copper-Amberlite IR-120 in Fixed Beds

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A PROBLEM of increasing interest is the treatment of dilute wastes, such as wash waters from metal pickling or plating operations. The recently developed resinous ion exchangers of high capacity seemed to be potentially attractive as a means of concentrating such wastes to the point that they could be economically recovered or more easily converted to insoluble forms for safe disposal.

In order to use resinous exchangers for this purpose, most effectively, it is necessary to learn the mechanism of the process (particularly the rate-determining step) and to measure the fundamental constants governing the exchange. These are the broad aims of this work. With an understanding of the mechanism and values of the apppropriate constants it should be possible to design a suitable ion-exchange unit for any given duty with a minimum of laboratory experiments.

Scope

Copper was chosen as the exchanging ion because it is frequently met in industrial wastes, because it is similar in behavior to other ions even more often met, and because it is easy to determine analytically.

The resinous (cation) exchanger Amberlite IR-120 was used because of its high capacity and its bead form which makes it less susceptible to attrition losses than earlier resins. Beaton and Furnas (3), who were among the first to consider ion exchange as a tool in the field, employed a carbonaceous exchanger in some of their

work. A comparison between Amberlite IR-120 and a carbonaceous exchanger is afforded by reviewing their results and those here reported, although there is a considerable difference in method of interpretation.

The *exchanging* ion was always copper in copper sulfate and the resin Amberlite IR-120, although in some runs a prototype exchanger known as XE-53 was used. Operation was always in the fixed bed, although a few static equilibrium runs were made.

The *exchanged* ion, i.e., the one which leaves the solid and enters the solution when copper is taken up, was usually hydrogen, but sodium, magnesium, and calcium were also studied in this role.

The entrance copper concentration was 5-101 meq./l. and it was usually made up from pure copper sulfate. In one case sulfuric acid was present in the influent. The range of these concentrations was similar to that found in brass wastes (4).

The linear velocity of the influent (based on an open cross section) was 6.8 to 80.6 cm./min.

The weight of resin used was 2.9 to 19.4 g. (measured as oven-dried (105° C.), hydrogen form). The size distributions were as follows:

1. XE-53

mm.	%
1.41 — 0.83	4.1
0.83 — 0.59	51.7
0.59 — 0.295	41.2
0.295 — 0.149	3.2
under 0.149	0.05

Limited cuts within the above ranges were used for special runs.

Both upflow and downflow operation was used, although the majority of runs were downflow. The temperature was that of the room except in one case.

Regeneration of these beds was not studied in this particular part of the work, but other regeneration results will be described in a subsequent article.

Results of Equilibrium Measurements

In order to find the basic rate mechanism an understanding of the equi-

librium relationship between copper and the exchanged ion is essential. Since the actual dynamic exchange in the fixed bed is accomplished equivalent for equivalent, it is necessary that the equilibrium be studied at *constant total normality*. Accordingly, solutions of copper sulfate and sulfuric acid each of a concentration of 19.5 meq./l. were prepared. These were mixed in varying proportions and allowed to react with the Amberlite IR-120 (hydrogen form) for two days at room temperature with intermittent agitation. The solutions were analyzed for copper and the copper content of the resin was determined by difference. In order to get the resin saturation corresponding to $C/C_o = 1.0$ a sample of resin was saturated with copper sulfate flowing through a small fixed bed for 24 hours. The resin was then analyzed for copper.

Results are given in Table 1 and are presented also in Figure 1.

2. IR-120

mm.	%
over 1.19	3.6
1.19 — 1.19	25.4
0.84 — 0.59	48.0
0.59 — 0.42	11.8
0.42 — 0.297	9.3
0.297 — 0.21	2.3

The same sort of experiments was carried out with magnesium sulfate in place of sulfuric acid except that the resin was initially in the copper form. Results are presented in Table 2 and are also shown on Figure 1.

These results are particularly interesting because they show the marked difference between the equilibrium relationships of these two systems. Copper-magnesium is essentially linear. Copper-hydrogen is nonlinear to a notable degree.
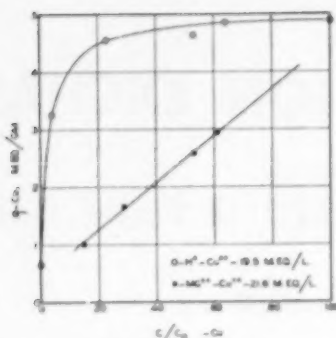
Fig. 1. Equilibrium.

Considering copper-hydrogen first, the equation for this exchange may be written:

$$Cu^{++} + 2HR = CuR + 2H^+ \quad (1)$$

Writing the Donnan equilibrium expression as Bauman and Eichhorn (2) have done

$$C_{CuR}{}^{++}\gamma_{CuR}{}^{++}C^2{}_{HL}{}^+\gamma^2{}_{HL}{}^+ = C^2{}_{HR}{}^+\gamma^2{}_{HR}{}^+C_{CuL}{}^{++}\gamma_{CuL}{}^{++} \quad (2)$$

Where subscripts R and L refer to resin and liquid phases.

Assuming for these dilute solutions that

$$\frac{\gamma^2{}_{HL}{}^+}{\gamma_{CuL}{}^{++}} = 1.0$$

and denoting

$$\frac{\gamma^2{}_{HR}{}^+}{\gamma_{CuR}{}^{++}} \text{ by } K$$

the above equation becomes

$$\frac{q/a}{(1-q/a)^2} = \frac{K\rho_A a}{Co} \frac{C/Co}{(1-C/Co)^2} \quad (3)$$

in which

a = total exchange capacity (meq./g. dry resin)

q = exchanging ion in exchanger (meq./g. dry resin)

ρ_A = apparent density of exchanger (g. dry resin/cc. wet)

Co = total cation normality in liquid phase

C = exchanging ion in liquid phase

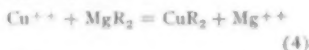Equation (3) is a general relation between q/a and C/Co for divalent-mono-

valent exchange and is plotted in Figure 2, with several values of the parameter $\dfrac{K\rho_A a}{Co}$. It is noteworthy that this parameter is a function of $1/Co$ and that when Co is small (dilute solution) this tends to make the equilibrium approach nearer and nearer to the extreme

$$q/a = 1.0$$

for all values of C/Co.

It may be noted that one may arrive at the same expression, differing only in the value of K, if one wishes to consider this a mass action equilibrium rather than a Donnan one. Since the value of K is not known and not necessary to the interpretation or use of the results, it is perfectly correct to consider Equation (3) as derived from the law of mass action.

Turning now to the copper-magnesium system, the equation for the exchange may be written

$$Cu^{++} + MgR_2 = CuR_2 + Mg^{++} \quad (4)$$

whence

$$\gamma_{CuL}{}^{++}C_{CuL}{}^{++}\gamma_{MgR}{}^{++}C_{MgR}{}^{++} = \gamma_{CuR}{}^{++}C_{CuR}{}^{++}\gamma_{MgL}{}^{++}C_{MgL}{}^{++} \quad (5)$$

Assuming

$$\frac{\gamma_{MgL}{}^{++}}{\gamma_{CuL}{}^{++}} = 1.0$$

defining

$$\frac{\gamma_{MgR}{}^{++}}{\gamma_{CuR}{}^{++}} = K'$$

then

$$\frac{q/a}{1-q/a} = K' \frac{C/Co}{1-C/Co} \quad (6)$$

Equation (6) is a general one for divalent-divalent exchange and is plotted in Figure 3 for the value of the parameter K' of one. It is noteworthy that the parameter is unaffected by Co and due to its definition, is probably not far from unity. This equation, like (3), may be arrived at equally well by the mass action concept.

Therefore, the two types of equilibria have been found. First, for copper-hydrogen the relationship is definitely nonlinear and approaches at low concentrations the extreme value of $q/a = 1.0$ regardless of the value of C/Co. This is characteristic of divalent-monovalent exchange. Second, for copper-magnesium the relationship is practically linear. For most divalent-divalent exchange systems (and probably many monovalent-monovalent systems, as well) the equilibrium is roughly of the same nature. Copper-calcium exchange is probably governed by this same general type of equilibrium. There is no exact confirming evidence in the case of calcium, however, for other reasons to be discussed later.

Results and Interpretation of Fixed Bed Runs

The results of some fixed bed runs are given in Table 3.

Thirty-eight column runs were made. In four of these, the liquid flow was upward, in the rest, the flow was downward. Usually, a fresh batch of exchanger was used for each run, and the bed was hydraulically classified before use. The possible mechanisms which may govern the exchange are:

1. Liquid diffusion to the particle (ion in and/or ion out)
2. Chemical reaction
3. Solid or pore liquid diffusion (ion in and/or ion out)

It is quite likely that all of them may be important, a situation of considerable mathematical difficulty. As an approximation, however, it is assumed that one of the above mechanisms governs the process, thus simplifying the solution considerably. For example, mechanism (1) might be more important for certain concentration regions and mechanism (3) for others. Boyd, Adamson, and Myers (5) have concluded that solid diffusion was governing at concentrations above 0.1 molal and that liquid diffusion or chemical reaction controlled below this value. Attention has been concentrated on the "break-through" curves and particularly on the earlier parts of them, because it is believed that these are of most practical importance. Interest for design purposes is in predicting time of breakthrough and emphasis on the relatively early portion of

TABLE 1.—EQUILIBRIUM IN THE COPPER-AMBERLITE IR-120 HYDROGEN SYSTEM

Co = 19.5 meq./l.

Q. Resin	cc. CuSO₄	cc. H₂SO₄	Cu in Liquid		Cu in Resin
			p.p.m.	C/Co	meq./g.
2.00	50	200	0.7	0.001	0.66
1.50	200	300	25	0.0405	3.26
1.00	250	100	142	0.23	4.55
0.80	350	50	324	0.53	4.65
0.40	200	0	396	0.64	4.86
...	...	...	620	1.00	4.90

the breakthrough is justified. Ordinarily concern is not with an exchanger when it is discharging an effluent almost up to the influent concentration of exchanging ion. However, it must be emphasized that the breakthrough must reflect what has long since taken place in the upper portions of the bed, and these portions have experienced the higher values of the curve. More will be said of this later.

In this investigation our attention is confined to the first two mechanisms above, and the development to follow is based on such mechanisms. The neglect of solid diffusion is justified by the consistent results and to a certain degree by run B-27 which is plotted in Figure 4. The feed was stopped after 1.30 l. had passed and was resumed only after a 22-min. delay. If solid diffusion gradients existed they would have tended to equalize in this period, and the curve would have shown a discontinuity. The difference between this behavior and that observed in this connection by Kunin and Meyers (12) for an anion exchanger should be noted.

The equation of conservation written for an ion exchange system is

$$V \frac{\partial C}{\partial x} + \frac{f}{\rho_A} \frac{\partial C}{\partial t} + \frac{\partial q}{\partial t} = 0 \quad (7)$$

This assumes no lateral concentration gradients in the solution or in the solid. It may be noted that the second term above refers to accumulation in the voids and may be omitted in the case of dilute solutions without serious error.

After superimposing on this a rate equation consistent with the above assumptions, one may integrate to get a suitable expression for C/Co as a function of time and position, i.e., the breakthrough curve.

The rate equations considered and the integrated results are as follows:

Liquid diffusion controls; nonlinear equilibrium (copper strongly adsorbed)

$$\frac{dq}{dt} = k_D SC \quad \text{until } q = a \quad (8)$$

$$\frac{dq}{dt} = 0 \quad \text{when } q = a \quad (8a)$$

This might be expected to be applicable to copper-hydrogen or copper-sodium. It will be noted that the assumption here is the extreme of this case. This assumption might be described as a case of zero back pressure until the solid is saturated, when the driving force drops to zero.

Klotz (11) has shown the integral expression to be

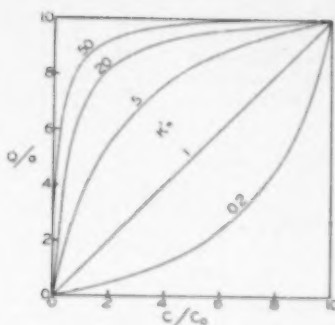$$\frac{C}{Co} = e^{\frac{k_D S}{V}\left(\frac{CoF}{a} - x\right)} - 1 \quad (9)$$

Fig. 2. Divalent-Monovalent Exchange Equilibrium.

Q. Resin	cc. CuSO₄	cc. MgSO₄	Cu.in. Liquid		Cu.in. Resin meq./g.
			p.p.m.	C/Co	
0.44	0	400	102	0.148	1.00
0.84	0	200	198	0.268	1.66
1.12	0	100	363	0.53	2.56
1.72	25	100	416	0.61	2.95

TABLE 3.

| Run No.	B-7		B-8		B-11		B-12		B-30	
Co (meq.Cu./l.)	5.0		101		20.0		20.0 with 17.0 H₂SO₄		19.5*	
V (l./hr.)	1.5		1.5		0.75		1.55		1.5	
Bed Wt. (g. dry H-R)	16.3		16.3		16.3		16.3		8.9	
Resin (type, form)	XE-53 H		XE-53 H		XE-53 H		IR-120-H		IR-120-H	
Size range (mm.)	normal		normal		normal		normal		0.59-0.42	
	y	C/Co	y	C/Co	y	C/Co	y	C/Co	y	C/Co
	10.82	0.010	0.494	0.004	2.805	0.004	2.070	0.002	1.190	0.008
	12.04	0.087	0.560	0.0217	3.035	0.024	2.455	0.006	1.390	0.018
	12.67	0.070	0.627	0.133	3.270	0.092	2.745	0.006	1.390	0.055
	13.59	0.233	0.697	0.314	3.410	0.176	3.110	0.051	1.495	0.262
	14.60	0.42	0.750	0.588	3.560	0.290	3.395	0.306	1.595	0.756
	15.00	0.51	0.805	0.81	3.730	0.408	3.540	0.410	1.685	1.00
	15.43	0.72	0.858	0.888	3.820	0.503	3.755	0.600		
			0.905	0.952	3.950	0.574	3.955	0.760		
			1.091	1.00	4.060	0.682	4.245	0.924		
					4.200	0.742	4.470	0.975		
					4.390	0.850	4.760	0.98		

* Temperature 63° C.
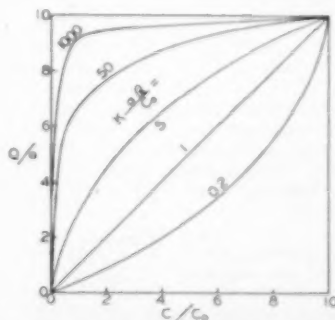
Fig. 3. Divalent-Divalent Exchange Equilibrium.

The voids accumulation term has been neglected in arriving at this and the first portion of the bed has been assumed to be saturated, a reasonable assumption for beds of ordinary experimental or industrial length.

Liquid diffusion controls; linear equilibrium

$$\frac{dq}{dt} = k_D S(C - C^*) = k_D S\left(C - \frac{q}{k}\right) \tag{10}$$

which, when it is realized that $q = a$ when $c = Co$, becomes

$$\frac{dq}{dt} = k_D S\left(C - \frac{qCo}{a}\right) \tag{11}$$

This might be expected to apply to copper-magnesium or copper-calcium.

This is analogous to the problem of heat transfer in fixed beds treated by Anzelius (1) and Schumann (14), the solution to which is presented in the curves of Furnas (9).

Chemical reaction controls: linear equilibrium

$$\frac{dq}{dt} = k_1 ac - k_2 q Co \tag{12}$$

This conforms to the stoichiometry of the copper-magnesium exchange. It may be noted that, since $dq/dt = 0$ when $C = Co$ and $q = a$, $k_1 = k_2$.

Thomas (17) gives a solution entirely analogous to that of Schumann differing only in the definition of the parameters.

Chemical reaction controls: nonlinear equilibrium

$$\frac{dq}{dt} = k_1(a - q)c - k_2 q(Co - C) \tag{13}$$

This has also been treated by Thomas (16) and leads to an integral expression of much interest but also of considerable difficulty to use in the analytical direction.

Chemical reaction controls: third order irreversible

$$\frac{dq}{dt} = k_{13}(a - q)^2 C \tag{14}$$

This would conform to the stoichiometry of the copper-hydrogen exchange. This has been treated by du Domaine, Swain, and Hougen (8). Their results were presented in the form of "water-softening performance charts."

Comparison of the Methods. There are two important problems here—the nature of the equilibrium (linear or not) and the rate-controlling mechanism (chemical reaction or liquid diffusion).
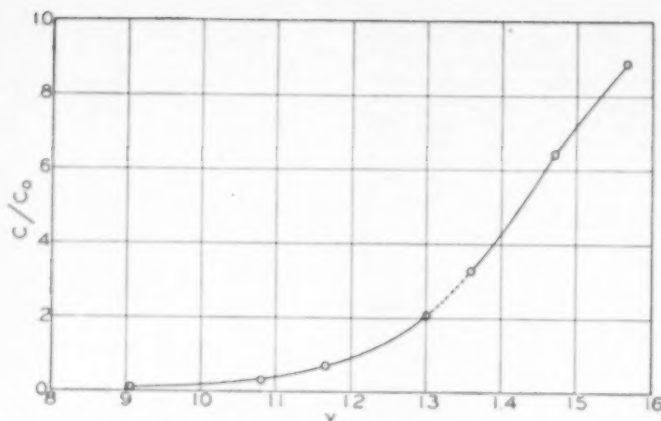

Fig. 4. Breakthrough Curve—Interrupted Run.

Assuming for the moment that diffusion may control there is still considerable difference in behavior between systems with nonlinear and those with linear equilibria. The difference is most notable in the behavior of the band, i.e., that region of the exchanger over which the liquid drops in concentration from its entrance value to approximately zero. This band clearly moves down the bed, and, when it reaches the end, the breakthrough phenomenon occurs. It is a consequence of the extreme nonlinear equilibrium ($q/a = 1.0$) that this band width is unaffected by the length of the bed. It can readily be shown that in the case of a linear equilibrium the band increases as the square root of the increase in bed length. This is an important difference and is particularly noteworthy when the design of large beds is to be considered.

According to Equation (9), one may plot the logarithm of C/Co against y and a straight line should result if the mechanism is correct. Departure from a straight line may well be expected at higher values of C/Co if solid diffusional resistance begins to play a part there. Such departures were found in these cases. The slope of this line is $k_D S Co / al'$ and the intercept is

$$-\left(\frac{k_D S x}{l'} + 1\right)$$

which permit the evaluation of $k_D S$ and a. The behavior of the quantity $k_D S$, with velocity, particle size, and other variables established whether or not the mechanism is obeyed. In particular, if $k_D S$ varies as the 0.5 to 0.8 power of the linear velocity and approximately linearly as S and is independent of bed

TABLE 4—VALUES OF MASS-TRANSFER COEFFICIENT $k_D S$ AND a FOR FIXED BED RUNS

Run	Ionic System*	F L./hr.	Co meq./l.	Resin Size Range—mm.	kDS g./hr.	a m.eq./g.
B-7	Cu—H	1.5	5	"normal—1"	1.43	4.4
8	Cu—H	1.5	101	"normal—1"	1.46	4.3
B-11	Cu—H	0.72	20	"normal—2"	0.83	4.2
12	Cu—H	1.55	20	"normal—2"	1.73	4.1
14	Cu—Na	1.5	20	"normal—2"	1.29	4.5
18	Cu—Ca	1.5	20	"normal—2"	0.95	3.6
B 26‡	Mg—Cu	1.5	20	0.59—0.42	0.92	3.7
28	Cu—Mg	1.5	21.5	0.59—0.42	1.1	4.9
30	Cu—H	1.5	19.5	0.59—0.42	5.5	4.9

* The exchanging ion is listed first, followed by the exchanged ion.
‡ Starting with this run, a different batch of Amberlite IR-120 was used.

"normal—1" Amberlite XE-53		"normal—2" Amberlite IR-120	
Diameter—mm.	%	Diameter—mm.	%
1.41 — 0.83	4.1	larger than	
0.83 — 0.59	51.4	1.19	3.6
0.59 — 0.295	41.2	1.19 — 0.84	25.4
0.295 — 0.149	3.2	0.84 — 0.59	48.0
Smaller than		0.59 — 0.42	11.5
0.149	0.05	0.42 — 0.297	9.3

length, inlet concentration, etc., this mechanism is confirmed.

Turning to the interpretation based on diffusion with a linear isotherm one finds it is not quite so straightforward. C/Co vs. y must first be plotted. The nature of the Schumann curves is that C/Co is a function of a variable proportional to y and of a parameter proportional to position in the bed or bed length. For this case the two variables are

$$u = \frac{k_D S C o}{a l'} y$$

$$v = \frac{k_D S x}{l'}$$

Thomas (17) has demonstrated a convenient method of getting the value of the bed length parameter from the slope of the C/Co vs. y curve at $C/Co = 0.5$ which is useful except with small values of the bed length parameter, v.

This method was usually used, but at low values of the parameter, comparison of the curves with those of Schumann was made instead. Once the parameters v and u are established $k_D S$ and a may be solved.

Again, since this $k_D S$ is a diffusion constant times the appropriate area it must vary properly with linear velocity and S and should be independent of x and show orderly variation with Co if the mechanism is to be confirmed.

The case of chemical reaction controlling with a linear isotherm the method is the same as that for diffusion except that the variables are defined as

$$u = \frac{k_1 C o y}{V}, \qquad v = \frac{k_1 a x}{V}$$

The behavior of this constant, k_1, with process variables will establish how well this mechanism fits. The constant, k_1, should, of course, be independent of velocity, particle size, C_o, and bed length.

These means of interpretation were tried and the methods based on liquid diffusion showed remarkable consistency and agreement with theory in the cases of copper-hydrogen and copper-sodium. These systems approach the extreme of the nonlinear equilibrium case ($q/a = 1.0$) for $C/C_o > 0$ and copper-magnesium with the linear equilibrium.

Results of this interpretation are shown in Table 4.

Discussion of Results

Preliminary. The A- series of runs (Fig. 5) for which values of $k_D S$ and a were not computed served to orient the work on a particularly important point. Runs A-1 and 2 (upflow) and A-3 and 4 (downflow) were made with the normal size distribution of the resin. These showed unmistakably that upflow operation was superior under these con-
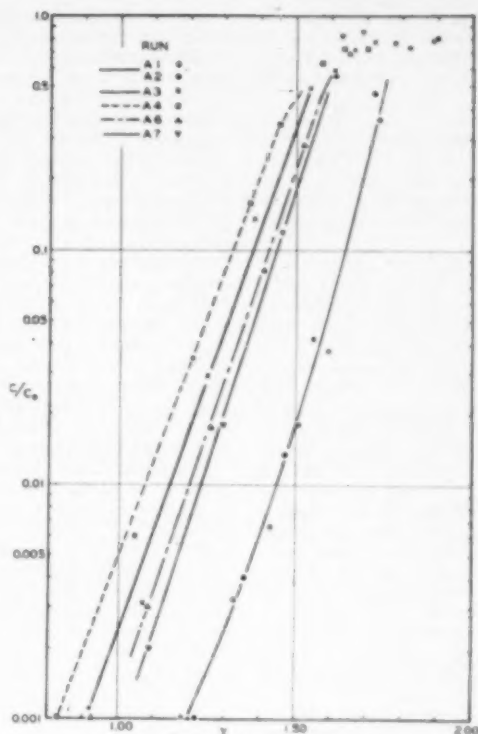

Fig. 5. Breakthrough Curves.

ditions. This can be explained by the reasonable hypothesis that

1. The breakthrough is particularly influenced by the particles at the end of the bed.

2. The end of the bed in upflow operation is the top where the smaller particles tend to be by hydraulic classification prior to the run.

3. The smaller particles are more effective if liquid or solid diffusion is the controlling step.

In order to confirm this A-6 (downflow) and 7 (upflow) were made, with closely sized resin (0.59-0.42 mm.). While the same sort of difference was observed they were much closer together, confirming the hypothesis, pointing up the importance of diffusion relative to chemical reaction rates, pointing out the importance of the variable particle size, and particularly indicating that in downflow operation the breakthrough is probably governed by the larger particles in the bed.

In spite of the superiority of upflow operation, all runs of the main series were downflow because of common industrial practice. The above is referred to again, however, in the discussion of particle size as a variable, for clearly

the larger particle sizes in a fairly wide distribution are most significant in downflow operation.

Reproducibility. Runs B-1 and 7, 4 and 4A, 15 and 16 and 21 through 23 were esentially check runs. The agreement among them is to be noted in Table 4 and such discrepancies as occur reflect experimental error and are in the assumptions of the interpretation. There are explainable differences such as, for example, improvement of experimental technique between runs B-1 and B-7. Thus, B-7 is undoubtedly the valid one.

Differences Among the Resins. Three resin samples, XE-53 and two batches of Amberlite IR-120 (the former an earlier version of the latter) were used. There seems to be a slight difference between the last sample of IR-120 and the first and the XE-53, as is most clearly seen by comparing the values of a, particularly runs B-21 through 25 with those before B-20. It is probable, however, that this is only an apparent difference, since all runs with the last batch of IR-120 were on closely sized resin, and the interpretation method should be more precise in this case. The effects of all

variables except particle size to be discussed below were determined on the same batch of resin, so any differences, if they existed, are unimportant to the conclusions.

Effect of Inlet Concentration. Runs *B-2, 7,* and 8 show the complete independence of $k_D S$ and *a* on this variable for copper-hydrogen as is reasonable with the liquid diffusion mechanism.

Effect of Bed Weight. Runs 4, 4a, 6 and 7 and runs *B-25, 21, 22, 23,* and 24 show the independence of $k_D S$ and *a* on bed length for copper-hydrogen. Runs 28 and 29 show the same for Cu-Mg, although there is a slight disagreement in *a*. This constancy of $k_D S$ with change in bed length for both types of equilibria is an important point of verification of the theory, although the bed length was varied over only a 2½-fold range here. It should be noted that Beaton and Furnas (*3*) have found a change in $k_D S$ (or its equivalent) with increased bed length for divalent-monovalent systems which does not seem reasonable. This is attributed to their interpretation by the Schumann curves, which assume the linear isotherm. Here the result in this connection shows the importance of the equilibrium function assumed and the superiority of the non-linear approximation used here for copper-hydrogen. Of course the Schumann method is correct for copper-magnesium. Boyd, Myers, and Adamson (*6*) have shown a slight dependence of $k_D S$ on bed length when sodium-cesium exchange was interpreted by the Schumann curves. In particular, the effect is about a 20% decrease in coefficient for a 15-fold increase in length. It is probable that this is due to the deviation of this system from a linear equilibrium. In this case, the equilibrium was less favorable to the exchange than the linear one assumed. The accumulated effects of solid diffusional resistance in a deep bed might also be offered as an explanation.

Effect of Velocity. Since all these runs were made in a bed of constant area (0.95 sq.cm.) the volumetric velocity is proportional to the linear. Thus the effect of this variable is clearly shown in runs *B-11, 7* and 3. These runs may be used to show that $k_D S$ varies as the 0.7 power of the liquid velocity which would be expected for liquid diffusion but which should not be the case for chemical reaction. This is one of the three principal points in support of our conclusion that liquid diffusion around the particle is the rate-governing step.

Effect of Particle Size. The effect of this variable is somewhat difficult to

evaluate from these data because of the rather wide particle-size distribution in certain runs and because the larger particles tend to be at the bottom of the bed as a result of prerun hydraulic classification. In downflow operation, as was used in all *B*-series runs, the larger particles at the bottom of the bed probably exert a preponderant influence on the breakthrough. Therefore in run *B-7* the effective diameter of the particles was taken to be 1.0 mm., the mean of the diameters of the largest particles present in appreciable amount. In runs *B-21* to 25 the mean diameter of the closely sized particles was 0.5 mm. Thus, since *S* varies inversely as the particle diameter, it is clear that the approximately doubled coefficients of run *B-21* to 25 are as would be expected for the liquid diffusion mechanism provided k_D did not vary with diameter. Heat-transfer coefficients on a volume basis as measured by Furnas (*9*) vary inversely as the 0.9 power of the particle size. Here the $k_D S$ is on a volume basis (strictly weight but proportional to volume) and can be compared directly with his coefficients in this regard. Agreement with mass transfer theory is therefore excellent. This is the second principal point in favor of this mechanism as distinct from one of chemical reaction in which no variation of velocity constant with particle size would be expected. There is, however, some arbitrariness in the selection of mean-particle sizes above and therefore it is felt that k_D should be considered as only relatively little affected if not absolutely unaffected by particle diameter.

Effect of Temperature. Run *B-30* was made at a temperature of 63° C. There is no effect on *a* but a pronounced effect on $k_D S$. While it is perhaps attaching undue weight to this one point it may be said that this run compared to *B-27* indicates a dependence of $k_D S$ on absolute temperature to the 4th power. Haslam, Hershey, and Kean (*10*) have found this same temperature dependence of liquid film coefficients in absorption towers. Interpreting this temperature dependence in another way one finds these data show an activation energy of about 2800 cal./(g. mole) (° K.), a typical figure for diffusion as distinct from chemical reaction. This is the third principal point in support of the authors' belief that this is a liquid-diffusion controlled process.

Effect of Initial Partial Saturation of the Resin. Runs *B-9* and 10 were made with the resin containing some considerable copper. It is clear that both *a* and $k_D S$ are reduced. The reduction of *a* is perfectly understandable, and in fact, if one adds the computed value of

a from the break-through curves to the known amount of copper initially on the resin one gets the value of *a* of approximately 4.5, the same as in the other runs. The lowered value of $k_D S$ is probably only apparent. It will be recalled that a driving force of $(C - O)$ has been assumed whereas in truth it is $(C - a$ small value). Thus all the $k_D S$ values are somewhat low because of the necessary simplification required to get a mathematical solution of the problem. Now when the bed contains some copper initially the true driving force is $(C - a$ somewhat larger value). Therefore the $k_D S$ values will be still smaller than the true values and somewhat smaller than the values obtained when no copper was on the bed.

Effect of Acid in the Influent. Run *B-12* was made with 17 meq./l. of H_2SO_4 in the feed as well as the copper. The value of *a* is somewhat reduced as would be expected, since the equilibrium will be somewhat less favorable to copper in the presence of this acid. The rather high value of $k_D S$ is unexplained and probably attributable to experimental error.

Elution. Run *B-20* was an attempt to elute the bed saturated with copper with sulfuric acid of 20 meq./liter concentration. Due to the selectivity with which copper is adsorbed (Fig. 1) one would not expect this to be successful, and it certainly was not as shown in Table 3. This should not be confused with regeneration where strong acid is used. In this case, as Equation (3) shows, the equilibrium is moved much more nearly to linearity by the high value of *Co* and regeneration certainly can be accomplished, as is well known, although probably not very efficient acid utilization will be experienced. Elution with $MgSO_4$ (Run *B-26*) was much better, as would be expected with the linear equilibrium involved. If the equilibrium were perfectly linear, it would be expected that this run would be identical to the corresponding exchange run with copper-magnesium system. The coefficient for the elution appears slightly lower, however.

System Copper-Sodium. Only one run (*B-17*) was made with this system, but it is clear that the value of *a* is the same as that with copper-hydrogen as would be expected. The value of $k_D S$ is somewhat less (about 94% of the Cu – H value) which would also be expected since the sodium ion should move somewhat more slowly than hydrogen.

System Copper-Magnesium. Runs *B-13, 28* and 29 show that this system (interpreted with the linear isotherm

assumption-Schumann curves) exhibited essentially the same values of a as corresponding hydrogen runs and still lower values of $k_D F$ (about 35% of that for $Cu - H$). Both these are in accordance with expectation if liquid diffusion controls.

System Copper-Calcium. Figure 5 shows that the shape of break-through curve obtained with the two runs with this system is not exactly similar to those predicted by assumption of either linear or irreversible equilibrium. No equilibrium measurements were made, but it is probable that copper-calcium is approximately linear, as in copper-magnesium, but that it is slightly less favorable. The break-through curves do not look like those of copper-magnesium, however. They have a slight curvature concave to the x-axis at relatively low values of C/Co which is not found in the Schumann curves at all. The equilibrium may be responsible for this, although possibly the solid diffusion resistance plays some part. Certainly curves calculated on the basis of solid diffusion mechanism by multiple incremental methods show this same concavity (15). In any case calcium does not seem to behave as the other ions, and the values of $k_D S$ and a in Table 4, evaluated as they were on the liquid diffusion and linear equilibrium assumption, should not be given much weight.

General Correlation. The values of $k_D S$ for copper-hydrogen have been corrected from the measured figure at the particular test conditions back to the standard reference conditions by the proper application of the effects found. Thus the standard conditions are:

Amberlite *IR-120*,
Size distribution—"as is," normal—2 of Table 4 (average governing particle size 1.1 mm.)
Linear velocity—1.58 l./(hr.)(sq.cm.) (downflow)
Temperature—26° C.

For runs differing in velocity $k_D S$ was multiplied by $(1.58/V^1)^{0.7}$. For runs differing in particle size $k_D S$ was multiplied by $(d/1.1)$ since 1.1 mm. is the average of the particle diameter of the larger sizes present in appreciable amounts for the standard conditions. For runs differing in temperature $k_D S$ was multiplied by $(299/T)^4$. These values were then averaged to yield 1.37 l./(g.)(hr.) (variation between 1.15 and 1.57). This may be readily converted to an "H.T.U." of 2.8 cm.

It may therefore be said that for the above conditions a value of $k_D S$ of 1.37 should be taken for copper-hydrogen. This value should vary as the 0.7 power of the linear velocity, as the fourth
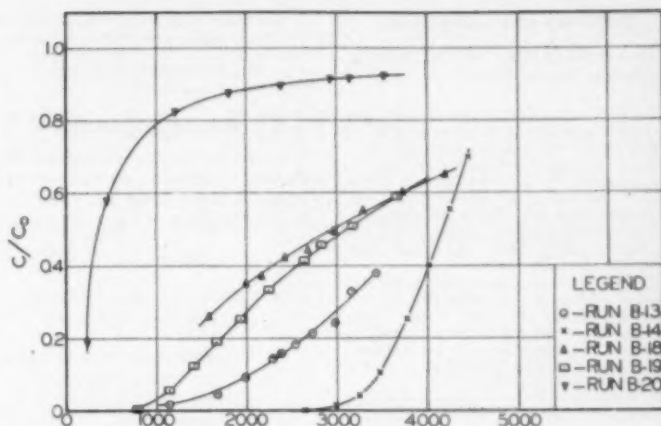

Fig. 6. Breakthrough Curves Runs B-13 Cu⁺⁺ — Mg⁺⁺, B-14 Cu⁺⁺ — Na⁺, B-18 and 19 Cu⁺⁺ — Ca⁺⁺, B-20 H⁺ — Cu⁺⁺.

power of the temperature, and inversely as the diameter of the particles. For copper-sodium about 94% of the above should be used. For copper-magnesium exchange, the coefficient is 35% that of copper-hydrogen. In this case the different kinetic behavior due to the linear isotherm should be borne in mind.

For all cases a reasonable average value of a is 4.5 meq./g.

Utility of Data for Design

The utility of these data may be demonstrated by the following two simple examples.

1. Suppose it was desired to remove copper from a solution of 10 meq./l. at the rate of 1,000,000 gal./day until it had leaked through to the extent that C/Co 0.05.
Suppose, further, that 5,000 lb. Amberlite *IR-120* in the hydrogen cycle were to be used at the previously described standard conditions. Complete regeneration is assumed although if it is not complete, correction need be made only in the x term.

Then

$$x = 5,000 \times 454$$
$$Co = 10$$
$$V = \frac{1,000,000 \times 3.785}{24}$$
$$C/Co = 0.05$$
$$a = 4.5$$

Substituting in Equation (9)

$$\ln 0.05 = \frac{1.37 \times 24}{3,785,000}\left(\frac{10y}{4.5} - 2,270,000\right) - 1$$

whence

$$y = 919,000 \text{ l.}$$

This corresponds to a break-through time of

$$\frac{919,000 \times 24}{3,785,000} \text{ or } 5.83 \text{ hrs.}$$

The per cent of the total capacity of the bed which is represented by the copper in the feed is

$$\frac{919,000 \times 10}{2,270,000 \times 4.5} = 90\%$$

The per cent saturation of the bed at the end of the operation, i.e., at $C/Co = 0.05$ is slightly less than this because of the leakage of copper through the bed when C/Co was rising to 0.05.

2. Suppose everything were the same except the substitution of the magnesium cycle for hydrogen.
In this case all quantities are the same except $K_D S = 0.35 \times 1.37 = 0.48$. The method is, of course, much different.

$$v = \frac{k_D S X}{V} = \frac{0.48 \times 2,270,000 \times 24}{3,785,000}$$
$$= 6.90$$

$$u = \frac{k_D S Co}{aV}$$

$$y = \frac{0.48 \times 10 \times 24y}{4.5 \times 3,785,000} = 6.76 \times 10^{-6}$$

With $v = 6.9$ and $C/Co = 0.05$ and $u = 1.7$ according to the Schumann curves.

Thus

$$y = \frac{1.7}{6.75 \times 10^{-6}} = 252,000 \text{ l.}$$

This corresponds to a break-through time of

$$\frac{252,000 \times 24}{3,785,000} \text{ or } 1.6 \text{ hr.}$$

The per cent of the bed capacity represented by the copper feed is only $C/Co = 0.05$ of

$$\frac{252,000 \times 10}{2,270,000 \times 4.5} = 14.8\%$$

This marked difference between the copper-hydrogen and copper-magnesium cycles in a critical item (the utilization of the resin) is in part due to the lower value of $k_D S$, but it is due mostly to the linear as distinct from the nonlinear equilibrium.

Summary and Conclusions

As a result of this work the following conclusions may be drawn.

1. Divalent-monovalent exchanges such as copper-hydrogen and copper-sodium on Amberlite IR-120 follow a nonlinear equilibrium in dilute solutions which may be approximated by the extreme $q/a = 1.0$. This is equivalent to assuming no back "pressure" until the resin is saturated.

2. Copper-magnesium exchange follows an approximately linear equilibrium over these concentration ranges.

3. Probably both liquid and solid diffusional resistances are important in this problem, but the early part of the breakthrough curve (which is the most important from the standpoint of design) is governed almost entirely by diffusion in the liquid around the particles.

4. Behavior of a divalent-monovalent exchange in a fixed bed may be interpreted, and it is believed the design of large beds can be accomplished by the equations

$$\frac{C}{C_o} = e^{\frac{k_D S}{V}\left(\frac{C_o V}{a} - x\right)} - 1$$

The value of $k_D S$ for copper-hydrogen is about 1.37 l./(hr.)(g.) with normal-size Amberlite IR-120, a downflow rate of 28.1 cm./min., and at room temperature. This $k_D S$ varies as the 0.7 power of velocity, inversely as particle diameter, as the fourth power of absolute temperature, and should be independent of other variables over the ranges here studied. In downflow operation of a bed of widely spaced particle size, the average size of the larger particles present in appreciable amounts should be used for interpretation and prediction.

For deep beds, the largest particles might be present in sufficient quantity to control the breakthrough. In deep beds, there is also a possibility that the apparent $k_D S$ would be reduced because of the accumulated effects of the deviation of the system from the mechanism and equilibrium assumed.

For copper-sodium the value of $k_D S$ is about 94% of the above.

The value of a is about 4.5 meq./g. for this resin.

5. Behavior of a copper-magnesium exchange in a fixed bed may be interpreted, and the design of large beds can be accomplished, it is believed, by the use of Schumann curves with the parameters

$$u = \frac{k_D S C_o}{a V} y$$

$$v = \frac{k_D S X}{V}$$

For copper-magnesium the values of $k_D S$ is about 35% of that for copper-hydrogen. The appreciable reduction in $k_D S$ for this divalent-ion system is another disadvantage to this ionic system compared to copper-hydrogen, less favorable equilibrium being the prime one.

6. Copper-calcium exchange does not seem to follow closely the theory of liquid diffusion with linear equilibrium. It is possible that solid diffusion, as well as non-linear equilibrium both contribute to this effect.

7. The behavior of a bed containing initially some of the ion to be exchanged can be predicted by correcting a for the amount there present and by recognizing that $k_D S$ will be reduced a little by this change with a nonlinear system.

8. For resins with a wide distribution of particle size upflow operation is to be preferred to downflow from the standpoint of the per cent of utilization of the capacity of the exchanger in a cycle.

Notation

a = total capacity of exchanger-milliequivalents/g. oven-dry $H\text{-}R$

C = concentration of exchanging ion-milliequivalents/liter

Co = initial concentration of exchanging ion or sum of concentrations of exchanging and exchanged ions-milliequivalents/liter

$H\text{-}R$ = refers to resinous exchanger in hydrogen form

K, K^1 = equilibrium constants

k_D = mass-transfer coefficient-liter/(gram)(hour)

q = concentration of exchanging ion in the exchanger milliequivalents/g. oven-dry $H\text{-}R$

S = surface area-sq.cm./g. oven-dry $H\text{-}R$

t = time-hours

T = absolute temperature ° Kelvin

u, v = arguments of Schumann curves

V = column flow rate-liter/hour

V^1 = flow rate-liter/(hour) (sq. cm.)

x = bed depth-g. of oven-dry $H\text{-}R$

y = volume of liquid through bed, liters

L = ions in liquid phase

R = ions within the resin particles

γ = activity coefficient

ρ_A = apparent density of exchanger particle-g. oven-dry $H\text{-}R$/cc./exchanger

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Discussion

L. C. Widdoes (National Dairy Products, Long Island, N. Y.): Approximately what percentage increase in capacity can you find on the upflow over the downflow for the commercial resins?

W. A. Selke: The increase in effective capacity is brought about by decreasing the width of the break-through band at the exit end of the column. Thus, the maximum fractional increase possible by any means is the width of the band, measured from the point at which the leakage reaches the maximum tolerable level to the point at which the resin is essentially saturated. Actually, upflow operation can be expected merely to reduce the band width, by a factor depending on the range of size of resin particles used. The band width also depends on ionic system and flow rate. Therefore, although with our short experimental beds, differences in effective capacity of 15% were noted, this effect might be greater or less in a different case.

L. C. Widdoes: Do you have any figures on other ions?

W. A. Selke: Although values of the mass-transfer coefficients were not obtained for other systems than the four mentioned in the paper, it is felt that estimates could be made for binary systems of other ions with copper.

L. C. Widdoes: You wouldn't be able to predict for sodium versus hydrogen?

W. A. Selke: Our data would not permit more than a rough estimate.

Anonymous: In connection with the Amberlite IR resins, did you have any trouble with decrepitation when rewetting?

W. A. Selke: Some decrepitation was observed, but it was not considered as presenting significant difficulty. In a system in which the resin is always kept wet, this trouble can be reduced.

(Presented at Forty-second Annual Meeting, Pittsburgh, Pa.)

LETTER TO EDITOR

ANALYSIS OF REACTION RATE DATA FROM FLOW SYSTEMS

Sir:

The enclosed note is submitted for publication in *Chemical Engineering Progress* in the hope that it will encourage a better-founded interpretation of reaction rate data in flow systems than is often used in engineering work. It points out a method which will materially shorten the labor of calculation in analyzing kinetic data without sacrificing any of the rigor of a proper analysis. I am well aware that this note contains nothing new in principle to academic investigators, but by personal experience I know that in industrial research and development departments there is a widespread feeling that the rigorous kinetic equations for flow systems are extremely complicated to use. It is in an attempt to dispel this misconception that the present note is offered.

July 21, 1950

Hugh M. Hulburt,

Washington, D. C.

THE purpose of this note is to point out a simple interpretation of the differential equation for the reaction rate under steady flow conditions in a cylindrical reactor with no pressure gradient and no radial velocity gradient (so-called "plug flow" conditions). A differential material balance at an arbitrary cross section of the reactor (*1, 2*) gives the equation

$$G \frac{dZ}{dx} = F(\rho Z) = F(C) \qquad (1)$$

where

Z = molal concentration of key component (lb.-moles/lb. fluid stream)

G = mass velocity lb./(sq. ft.) (hr.)

ρ = fluid density (lb./cu. ft.)

x = distance from reactor inlet (ft.)

$F(\rho Z)$ = lb.-moles of key component produced/(hr.) (cu. ft.)

C = lb.-moles/cu. ft.

The space velocity, S_o, and its reciprocal, the nominal contact time, t_o, based on feed rate *at reaction temperature and pressure*, are introduced by the relationship

$$1/t_o = S_o = G/\rho_o L \qquad (2)$$

where

ρ_o = density of feed

L = length of reactor

Equation (1) can now be integrated formally to give

$$\int_{Z_o}^{Z_1} \frac{dZ}{F(\rho Z)} = t_o/\rho_o \qquad (3)$$

This equation defines the product composition, Z_1, in terms of the nominal contact time, t_o. The usual kinetic data obtained by varying space velocity at constant feed composition (isothermal reactor) can be represented graphically in this way.

Differentiating Equation (3),

$$\rho_o \frac{dZ_1}{dt_o} = F(\rho_1 Z_1) \qquad (4)$$

This is the fundamental differential equation of the plug flow reactor. It also applies along any line of constant mass velocity in a reactor with a radial velocity gradient when radial diffusion may be neglected.

Note that $\rho_1 Z_1$ is the concentration, C_1, in the product in the usual units of lb.-moles/cu.ft. Hence $F(\rho_1 Z_1)$ is the usual rate expression as written for a static system. E.g., for a first-order reaction, $F(C_1) = k_1 C_1$.

The left-hand side of Equation (4) can be written

$$\rho_o \frac{dZ_1}{dt_o} = \frac{d}{dt_o}\left(\frac{\rho_o}{\rho_1} \cdot \rho_1 Z_1\right) = \frac{d}{dt_o}\left(\frac{\rho_o C_1}{\rho_1}\right) \qquad (5)$$

In a constant pressure reactor, the ratio ρ_o/ρ_1 is just the moles total product per mole total feed, and hence, equal to the ratio S_1/S_o of the space velocity

based on products to that based on feed. Thus Equation (4) becomes

$$\frac{d}{dt_o}\left(\frac{S_1}{S_o} C_1\right) = F(C_1) \qquad (6)$$

If Equation (6) is to be integrated, S_1 must be expressed as a function of C_1 and no particular advantage can be claimed for this expression over any other. Of course, any consistent method of transforming the concentration units in Equation (1) will give correct results (*2, 3*).

However, when reaction velocities are to be evaluated by taking the slope of a composition-time curve, use of the composition function $S_1 C_1/S_o$ has definite advantages. A plot of $S_1 C_1/S_o$ vs. $t_o = 1/S_o$ gives a curve whose slope at any value of t_o is equal to the differential reaction velocity to be expected in a nonflow system at that same contact time, viz., $F(C_1)$. E.g., if the mechanism has the quasi-elementary form

$$F(C_1) = k_n (C_1)^n \qquad (7)$$

a plot of log $(d/dt_o)(S_1 C_1/S_o)$ vs. log C_1 will give a straight line whose slope is the apparent reaction order, n.

The analysis of differential rate data thus determined proceeds exactly as for the familiar nonflow systems. By taking $S_1 C_1/S_o$ as the composition variable, the truly chemical rate factors are displayed unencumbered by the effects of mean density change in a constant pressure continuous reactor. This separation of chemical and physical factors is often a help in diagnosing apparent anomalies.

The factor S_1/S_o is appreciable only for gas-phase reactions in which the moles of product differ from the moles of feed, but should not be neglected in this case when reaction is more than about 20% complete.

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INDUSTRIAL PROCESS SOLUTIONS

Some Methods of Automatically Controlling Chemical Concentrations

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In recent years industrial instruments have proved both practical and beneficial in the regulation of chemical concentrations of process liquors. The present paper deals with several systems utilized for this purpose in modern plants, including brief descriptions of component parts and typical industrial control combinations.

The scope of the paper is confined to industrial electrometric measurements (pH, electrolytic conductivity, and Redox) and alternate methods of specific gravity measurement, including differential pressure meters and electric hydrometers. These are considered in various control combinations with proportioning pumps, dry feeders, automatic weighing devices, and special control valves for slurries and low flows. Recording spectrometers and gas analysis equipment are not included.

IN a chemical process, automatic control of such variables as temperature or flow is often only an indirect method of regulating other desired properties of the process solution—such as chemical concentration, specific gravity, viscosity, or refractive index. Particularly in continuous processes where the composition of feed stocks or raw materials can vary during operation, automatic controllers which do not reflect such changes in the measurements are powerless to compensate for them. Modern instrumentation offers controllers which can continuously and directly analyze many chemical or physical properties of a process solution as the basis for automatic control.

In the present paper, commonly available systems are described for the control of chemical concentration, based upon measurement of pH, oxidation-reduction potential, electrolytic conductivity, or specific gravity. Following a brief discussion of each type of measurement as a method of determining chemical concentration, consideration is given to practical means for actual regulation of the control agent flow in the process.

pH Measurement. As a direct measure of effective acidity or alkalinity in an aqueous solution, pH offers a means of chemical concentration control which is finding wide application in modern chemical processing. Illustrative of its industrial use is the system shown in Figure 1 for the preparation of disodium phosphate. Soda ash enters a mixing tank, as shown. A flow-type element is installed in a sampling line in the salt outlet pipe and is connected to a recording pneumatic controller through an amplifier unit. The pH controller regulates the inflow of phosphoric acid (the control agent) by positioning a diaphragm motor valve.

The first consideration in such control
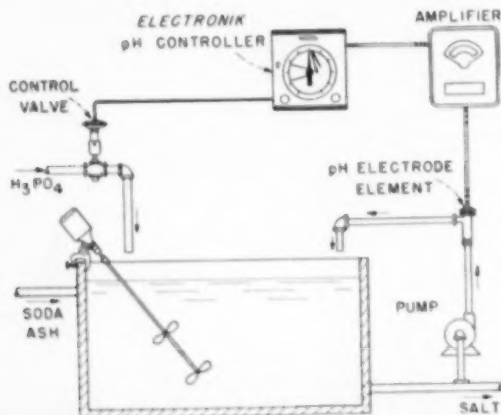
Fig. 1. Typical pH Control System Used in Manufacture of Disodium Phosphate.

applications is the rate of change in pH as control agent is added. Typical titration curves are plotted in Figure 2. In general, it will be noted that at first the slope of the pH curve changes slowly with addition of acid, then much more rapidly as neutrality is approached, and again slowly after the neutral point is passed. The rate of change in pH is seen to vary widely along these curves.

For optimum automatic control, this characteristic must be taken into account. When small additions of the control agent cause rapid and large changes in pH, such as exhibited by the mixture of a strong acid and base near the neutral point (A), wide cycling about the control point can easily result and straight-line control records are difficult to obtain.

Use of a buffer acid or base as the control agent, where possible, or natural buffers in the solution often simplify the control problem by providing a more gradual slope in the curve (see point D). Otherwise, a larger mixing chamber is recommended so that the volume of the solution itself tends to slow down the rate of change in pH.

On the other hand, the slope of the pH curve is seen to be almost horizontal at points B and C where a large excess of the strong acid or base is present. Control in this region is obviously impractical, since pH measurement is insensitive to changes in the control agent. Direct measurement of pH as a means of concentration control is generally confined to dilute solutions, or more concentrated solutions near the neutral point.

Various types of glass-measuring electrodes and calomel-reference electrodes are available for use in immersion or flow-type pH measuring assemblies to suit applications in the range of temperatures from 50 to 212° F. and pressures up to 30 lb./sq.in. Conditions exceeding these limits can frequently be handled by the continuous removal of a sample through a heat exchanger and/or pressure-reducing valve.

The temperature effect on the pH measuring electrode is automatically compensated by a resistance thermometer bulb in the electrode assembly so that the potential developed is that due to the pH of the solution at the existing temperature.

From the control standpoint, it is highly desirable that the treated liquid and control agent be mixed intimately as rapidly as possible. This may require an additional mixing tank with suitable agitator or a pipe line mixer with baffles (2).

Capacity in the form of a mixing tank is helpful also in dampening out rapid changes in pH or flow of the liquid to
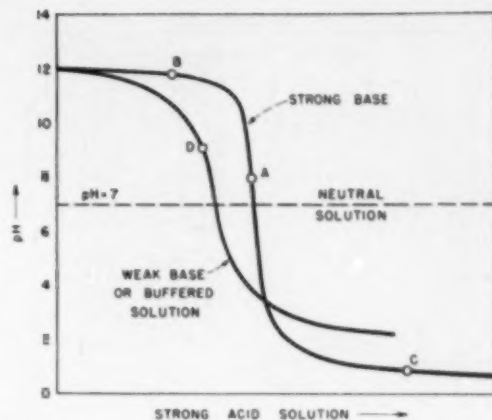
Fig. 2. Typical Neutralization Curves of Strong and Weak Base with a Strong Acid.

be treated. Furthermore, some retention time is usually required to enable the reagents to react prior to pH measurement.

The glass electrode is quite sensitive to changes in pH and, when combined in an electronic measuring circuit, provides a system with high over-all sensitivity. The introduction of capacity for mixing and reaction, however, necessarily produces a time delay in measurement of pH changes. This lag usually dictates the use of a proportional controller with provision for wide proportional band adjustment and automatic reset. In some cases, the need for rate response (derivative action) is indicated.

Redox Potential. Although not used industrially to the extent of pH, Redox potential is worthy of consideration by the process engineer. In many chemical reactions, a given ion in solution undergoes oxidation or reduction, either completely or partially, and it is important to control the reagents involved so that

the process proceeds as desired. By the use of electrometric equipment similar to that for pH measurement, it is possible to measure the potential developed due to the relative amounts of oxidant and reductant in solution. This is known as the oxidation-reduction or Redox potential.

An example of this form of measurement applied industrially is found in the extraction of bromine from sea water where oxidation potential guides the process at several stages (3). In the steaming-out towers, for example, bromine is removed from HBr by the addition of chlorine. An electrode element is placed in the effluent line from each tower, measurement of oxidation potential being used to throttle the addition of chlorine.

Redox potential is influenced by both temperature and pH. These factors must be investigated, and where they are not sufficiently stable, must also be controlled. Aside from the fact that this potential usually must be plotted experi-

Fig. 3. Several Curves of Conductivity vs. Concentration Plotted at 65° F.

Fig. 4. Differential Pressure-type Specific Gravity Measuring System Employing Air Purge.

compensation involves the use of a second sealed cell immersed in the process solution together with the measuring cell and connected in the instrument circuit such that it cancels out the effects of temperature. Enclosed in the additional cell is a sample of the solution being measured at a concentration equal to that to be maintained in the process.

A second means of automatic compensation involves the use of a temperature-sensitive element installed in the process solution and connected electrically in the measuring circuit to compensate for temperature variations.

Conductivity cells are suitable, in general, for pressures up to 150 lb./sq.in. and temperatures up to 200° F. They can be equipped with molded-rubber or stainless-steel protecting tubes to minimize possible breakage in the process. Sample cooler assemblies complete with cell are available to withstand inlet pressures up to 600 lb./sq.in.

Specific Gravity. For some time, specific gravity has been a useful solution property to measure as an indication of chemical concentration. Several practical industrial systems are available for its measurement and control.

Differential Pressure System. Shown schematically in Figure 4 is the adaptation of a standard differential pressure-type instrument for the measurement of specific gravity. Air is bubbled into a sampling chamber through dip tubes immersed in the liquid under test so that any difference in air pressure impressed on the manometer is due to changes in the specific gravity of the measured liquid.

A *reference chamber* is used to suppress the initial differential pressure produced by the dip tubes and thus provides a zero reading on the instrument corresponding to the minimum specific gravity to be measured (*1*). Various designs of differential pressure meters are available, including types which permit electric or pneumatic transmission of the measurement to remote recording controllers.

Electric Hydrometer. Shown in Figure 5 is the detecting element for specific gravity in which the position of a totally submerged plummet (float) is detected by an electrical system employing an electronic potentiometer. The plummet is so designed that, at the center of the gravity range, it will support half the weight of a calibrating chain attached to the side of the sampling chamber. When the gravity changes above or below its mid-value, the increase or decrease in buoyancy of the

mentally under actual operating conditions, considerations in its application are much the same as previously discussed for pH.

Conductivity. In contrast to pH or Redox potential measurements, electrolytic conductivity is affected by all ions present in a solution. As a means of chemical concentration control, therefore, it offers some advantages, particularly in more concentrated solutions, although it is also suited to measuring low concentrations.

The measuring element comprises two electrodes or plates insulated from each other in what is commonly called a "cell." Conduction of current due to the ions in solution is measured by an electronic potentiometer in terms of the reciprocal ohm or mho. With only a single electrolyte present in solution,

conductivity is a direct measure of chemical concentration of the dissociated ions.

As shown in the curves of conductivity versus concentration (Fig. 3), it is necessary to consider the slope in the region of desired concentration control. Regulation of hydrogen chloride concentration in the vicinity of 9% is seen to be feasible, but at 18% where the curve reaches a maximum, it is obviously not suited because decreasing conductivity values might be indicative of either decreasing or increasing concentrations. In mixtures of electrolytes, it is usually desirable to test the solution experimentally to determine whether or not useful relationship between conductivity and concentration is present (*8*).

Conductivity is known to be affected by temperature as well as ion concentration. One method of temperature

Fig. 5. Schematic View of Electric Hydrometer Detecting Element.

plummet causes it to rise or fall accordingly, supporting more or less of the chain weight until a new position of equilibrium is established.

The vertical position of the plummet is translated into an indication of specific gravity through the use of an inductance pickup arrangement. A magnetic core inside the plummet and a coil winding outside the sampling chamber form a differential transformer which is connected in an electric circuit varying the voltage to the recording potentiometer.

The freely suspended plummet and electrical pickup arrangement form a highly sensitive and accurate measuring means. The system is accurate to as little as two units in the fourth decimal place, depending upon the gravity range. Full-scale ranges as narrow as .005 are available within the limits of 0.8 to 3.5 specific gravity.

Compensation for variations in process fluid temperature can be automatic over a wide range. Solution temperatures can be as high as 392° F. or as low as −112° F. and pressure, up to 150 lb./sq.in. in standard models.

Control Valves. The simplest form of a final control element for regulating control agent flow is the conventional diaphragm motor valve. This air-operated, sliding-stem-type valve provides wide-range throttling control of flows with a high degree of precision in response to air-pressure changes from a pneumatic controller. It can be supplied with a small valve body and plug suitable for low flows. The more refined types of automatic control, such as proportional with automatic reset, are more easily incorporated in such a pneumatic system than in its electric counterpart.

Where the control agent is a slurry or contains suspended solids which might tend to clog the conventional valve, a Saunders patent design is preferable. This valve throttles the flow by means of a flexible diaphragm which is pressed toward a raised seat, cast in the valve body. Even in a nearly closed position, it provides a flow path free of obstructions and tends to be self-cleaning after having been closed. Both the body and diaphragm are available in a variety of construction materials to handle highly corrosive fluids.

Controlled Volume Pumps. As a final control element to be operated by a concentration controller, positive displacement-type pumps offer some advantages over the conventional control valve, particularly in the regulation of low flows

Fig. 6. View of Electric Hydrometer.
Shows, at left, measuring unit; at right, electronic recorder—range
1.075 to 1.115 specific gravity.

(down to a few cubic centimeters per hour) and flows at high pressures (up to 20,000 lb./sq.in. in smaller sizes). They meter the flow accurately at the prescribed rate regardless of varying pressures up- or downstream (4-6).

Controlled volume pumps are supplied in types suitable for operation by either electric or pneumatic proportional controllers, which can adjust either the speed or stroke as a means of varying the control agent flow. Where the process input varies over a wide range in rate of flow or composition, automatic adjustment of both speed and stroke can be used—the motor speed, for example, being governed by a flow meter installed on the input flow line, while the length of stroke is set by a pH or conductivity controller on the output flow line.

As previously mentioned, control directly from such measurements as pH or conductivity may be impractical when the control point lies on a relatively flat portion of the process reaction curve. In such cases, continuous and automatic titration can be used for concentration control by means of the Milton-Roy Titronic system, shown schematically in Figure 7.

A duplex controlled volume pump constantly withdraws a small sample from the process output, and at the same time draws a metered quantity of a standard titrating solution—the two entering a common mixing chamber in which an element for pH, Redox, or conductivity is installed. The strength of the standard titrating solution and its rate of addition are adjusted so that the resultant mixture exhibits a suitable reaction curve (7). The measurement
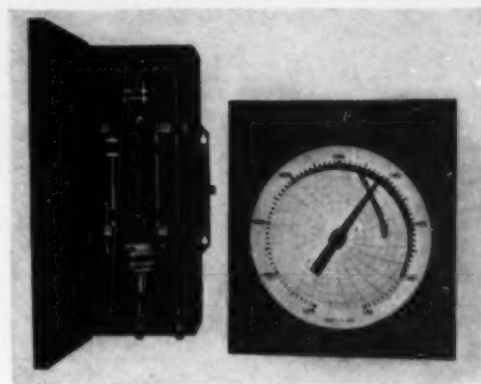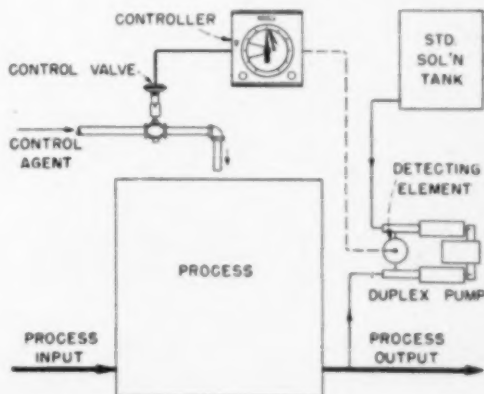
Fig. 7. Schematic Diagram of Duplex Pump Used in Titration System for
Chemical Concentration Control.
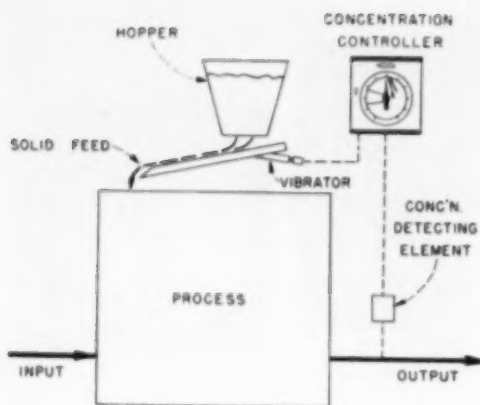
Fig. 8. Typical Concentration Control System With Vibrating Feeder as Final Control Element.

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can then be used to control concentration by regulation of the control agent as illustrated.

Dry Chemical Feeders. In chemical reactions, the control agent or second feed to the process, may be dry chemical and require the use of a dry feeder. A typical system is illustrated schematically in Figure 8. Impulses to an electric vibrator are regulated by a recording controller for pH, conductivity, or other selected variable. Systems utilizing disc-type volumetric feeders, bin valves, variable-speed conveyor belts, or other dry-feeder designs can be similarly applied to suit the characteristics of the chemical.

Where it is feasible to deliver the dry chemical on a constant weight basis and regulate the liquid flow to the process, a system, such as illustrated in Figure 9 can be used. The dry-feed system, shown on the left, employs a conveyor scale with variable-speed motor drive governed by a weight controller. This latter instrument is conventional recording controller with an inductance bridge receiving system commonly used for electric flow transmission. With constant weight feed to the process, concentration is controlled by regulation of the liquid input through a diaphragm motor valve operated by the concentration controller.

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Discussion

G. E. Haddeland (Shawinigan Chemicals Limited, Shawinigan Falls, Que.): You indicated a process vessel or system in your diagrams. Is the size of that vessel or system an important feature of the control system, or is there any relationship?

S. D. Ross: You are perfectly right. There was no relationship meant to exist between the size of the process tank and the control system but the size of the mixing vessel is an important consideration in the application of any type of electrometric or similar measurement. I have heard it said that the volume of the vessel should be 3 to 10 times the rate of flow into the process and that the exact value within those limits depends upon the other factors considered: the process reaction rate, the time it takes the chemical to react, and the degree of mixing present.

T. K. Sherwood (Mass. Inst. of Tech., Cambridge, Mass.): You don't have a relation for your reaction rate with the size of the tank?

S. D. Ross: No. I'm afraid it is up to the chemical engineers to develop that. There is a paper by H. C. Frost (Lt. Cited (2)), in which he goes into great detail on the design of a process with those factors in mind. The instrument engineer or an engineer with an instrument company is handicapped in obtaining such data. That is why we believe the process engineer needs a general knowledge of these measuring systems. He is the one who can best apply them.

(Presented at Twelfth Regional Meeting, Montreal (Que.), Canada.)

Fig. 9. Typical Concentration Control System With Dry Chemical Feed on Constant-weight Basis and Control Valve on Fluid Line to Process.

POTASH PRODUCTION AT CARLSBAD

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International Minerals and Chemical Corporation, Carlsbad, New Mexico

THE potash industry of the United States became a dynamic factor in the chemical economy of the country in the early 1930's when mining of potash ores at Carlsbad was begun. In the 17-year period from 1932 to 1949 production increased fifteen-fold to enable the country to meet the greatly increased demand of war and postwar conditions. Today the annual production rate approximates 1,000,000 tons K₂O and is still rising. Present producers in the Carlsbad field are expanding facilities with one new concern sinking a shaft and planning to erect a refinery to treat the ore. Three additional companies are doing exploratory work to find and delineate ore bodies. One of these three is experimenting with solution mining instead of the conventional methods now in use.

Agriculture furnishes the major sales outlet for the industry, absorbing approximately 90% of the total production. The balance goes into the manufacture of miscellaneous chemicals, chief among these being potassium hydroxide, potassium carbonate, and potassium chlorate.

Potash is one of the few commodities as yet relatively unaffected by the rising price trend, the selling price f.o.b., producing points has remained practically constant for the past 12 years. Since the term potash covers all naturally produced potassium compounds, prices are based on the hypothetical K₂O content potassium of the material involved.

History

One of the early developments in chemical production in this country was the manufacture of potash from wood ashes which was started in New Hampshire in 1632. In 1750 this material was being exported to England and in the period just prior to the Civil War the value of these exports climbed to $2,000,000 anually. In 1861 potash salts in commercial quantities were discovered in Germany and by 1872 our domestic production had practically ceased in favor of German imports. An international price war and the onset of World War I revived interest in domestic sources of potash. The existence of potash in the Permian Basin had been known since 1842 which made it logical to concentrate the exploration program in this area. Financed by grants from Congress, Government agencies began an intensive search for potash in 1911. Private interests cooperated by watching wells drilled for oil and water and potash was found in a water well in Dickens County, Tex., in 1912. Polyhalite was identified in an oil well test in Midland County, Tex., in 1921.

In 1925 sylvite was discovered in a well drilled for oil about 20 miles east of Carlsbad. A second hole, using a core drill was immediately sunk which indicated the existence of a deposit of sufficient quality and quantity to justify its development. Spurred by this, Government agencies (under the Shepard Bill) and private interests began intensive prospecting by core drilling. These activities resulted in the establishment of the reserves sufficient for a hundred years even at the present rate of consumption and neglecting those now considered uneconomical such as the polyhalite deposits.

Geology

The potash deposits of New Mexico and West Texas are located in the Permian Basin of the Southwest Mid-Continent area. The geology of this region is complex and many of the problems remain unsolved, in spite of intensive work by petroleum geologists and others who are interested in the stratigraphy and occurrence of the potash and magnesium salts.

Probably the greatest Permian record in the world—certainly in the United States—occurs in West Texas and Southeast New Mexico, where Permian strata total about 14,000 ft. in thickness. This area was a basin which was occupied most of the time by a seaway which entered through Mexico and toward which drainage converged from the eastern interior and from what is now the Rocky Mountain Region. Within this major depression, known as the Guadalupe Basin, there were two sub-

Aerial View Potash Co. of America Refinery.
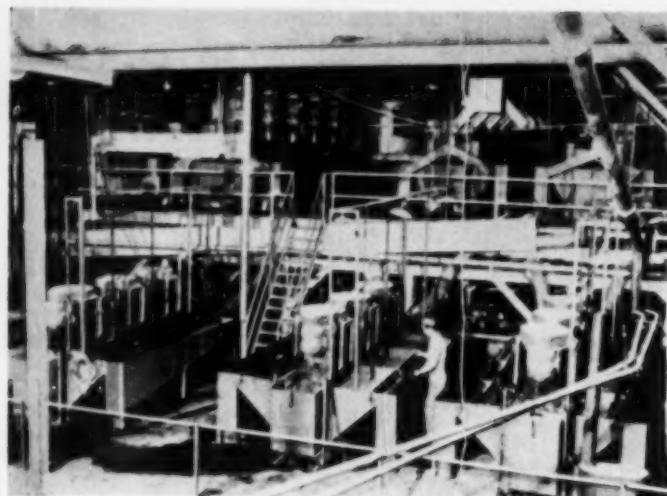
Rougher Flotation Cells in Upper Background.
Cleaner Flotation Cells in Foreground.
International Minerals & Chem. Corp.

sidiary and rapidly sinking areas, the Delaware Basin in Trans-Pecos, Texas, and Southeast New Mexico, and the Midland Basin of West-Central Texas.

The Delaware Basin is a pear-shaped area occupying approximately 15,000 sq. miles. It covers portions of Eddy and Lea Counties in New Mexico and extends as far south as the Glass Mountains in Brewster County, Tex.

During the sinking of these subsidiary basins the remainder of the Mid-Continent Area was emerging into lowlands, the climate became increasingly arid and warm, and local conditions in the Guadalupe Basin gave rise to exceptional Permian deposition. Excessive evaporation was matched by a steady flow of the marine water from the basin to its bordering shallow fringe.

This caused excessive deposition of limestone along the margins of the Delaware Basin, where the water was warmed and began to suffer concentration. The result was the growth of reef-like limey banks of algal origin between the deeper basin and the vast marginal lagoons. The marginal lagoons tended to become salt pans in which red muds from surrounding lands settled to intertongue with deposits of gypsum, anhydrite and salt. Nearly pure limestone was accumulated over the reef areas and dark shales, dark limestone and silty sandstones were deposited in the deeper waters of the basin. Thus, in this region the Permian strata of any given time commonly present three distinct faces, one of the lagoonal deposits (slabby limestone, gypsum, salt and red beds), one of the massive reef limestone, and a third of normal marine strata, each grading locally into the other with astonishing rapidity.

Finally, during the last epoch of the period, the marine water shrank within the Delaware Basin, which became a dead sea, almost completely surrounded by a reef, and vast quantities of anhydrite and salt were deposited. Red muds from the surrounding desert wastes then washed in and filled the basin and these formed the final Permian strata. In the center of this basin in the southeast corner of New Mexico, deep wells have revealed some 4000 ft. of salt, anhydrite and red beds above the youngest of the fossiliferous marine sediments. These constitute the Ochoa series of the Permian and include the chief potash salt deposits of the Western Hemisphere. Thus the present concern is with the evolution and current condition of a fossil sea, and as the mine openings advance one is permitted to visualize in part the sequence of winds and storms and calms, the elevation and subsidence of the basin floor and the periodic freshening and concentration of its contained waters.

The principal nonpotash gangue minerals are halite (NaCl), anhydrite ($CaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$) and kieserite ($MgSO_4 \cdot H_2O$). The succession of beds vary widely in appearance through the section. In places several feet of clear white to pink salt have been precipitated. At other levels the beds are mixed with layers of wind-blown clay at intervals of 1-3 in. apart, while at still other levels beds up to 3 ft. in thickness are predominantly of clay impregnated with salt crystals.

The potash deposits now being mined are at the northernmost end of the Delaware Basin about 20 miles east of Carlsbad. The potassium minerals are the products of the last stages of evaporation; consequently the horizons at which they occur are found in the upper salt strata. The top of the salt is under 400-500 ft. of permian beds consisting of red shales and sands interbedded with anhydrite, gypsum and limestone. Sev-
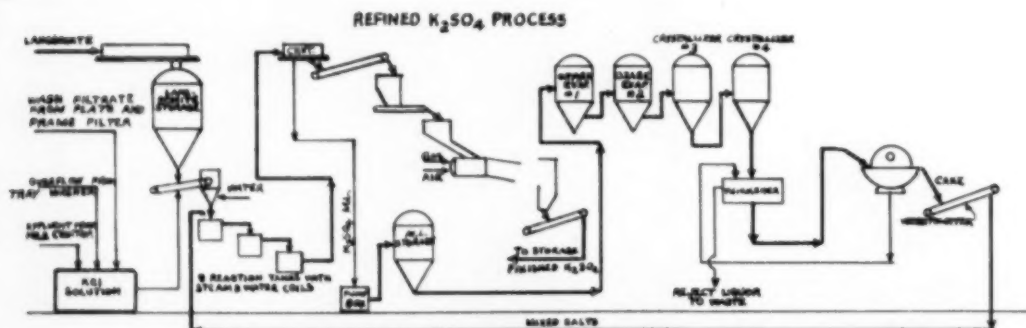
Fig. 1. Flow Sheet of Potassium Chloride and Potassium Sulfate Process. Refined K₂SO₄ and ▶

eral water horizons occur in these beds which must be sealed off in the mine shafts. The bittern salts are interbedded with halite and occur at intervals of about 50 ft. The uppermost bed is found at about 750 ft. below the surface and contains carnallite. In the southernmost part of the field on International's ground, two beds of langbeinite and mixed langbeinite-sylvinite are found at 800 and 850 ft. respectively, the former being the only known commercial occurrence in the United States. At 900 ft. a stratum of sylvite is found. The stratigraphic sequence of these beds indicates that the cycle of deposition was periodically interrupted and renewed. However, the order in which the bittern salts occur follows a normal path predictable from available solubility data.

Mining

The first mining in the district was by U. S. Potash Co. in 1931. Production was at the rate of 200 tons/day and the ore was trucked to Carlsbad to be shipped as manure salt. Mining methods used were those common in metal mining practice.

Potash Company of America began producing early in 1934, also at a rate of 200 tons/day. This company, was managed by men who had a coal-mining background and so coal-mining methods were instituted.

International Minerals & Chemical Corp. began mining in 1940 using coal-mining methods with the operation entirely mechanized. The undercutting and drilling machinery used by the other mines was supplemented by caterpillar-mounted conveyor-type loaders and rubber-tired double-trolley shuttle cars to move ore from the face to the mine cars.

Mine faces are undercut to a depth of 9 ft. This allows the blast to make a clean break at top and sides and also provides a smooth floor for further advance into the seam.

Drilling is done with post-mounted
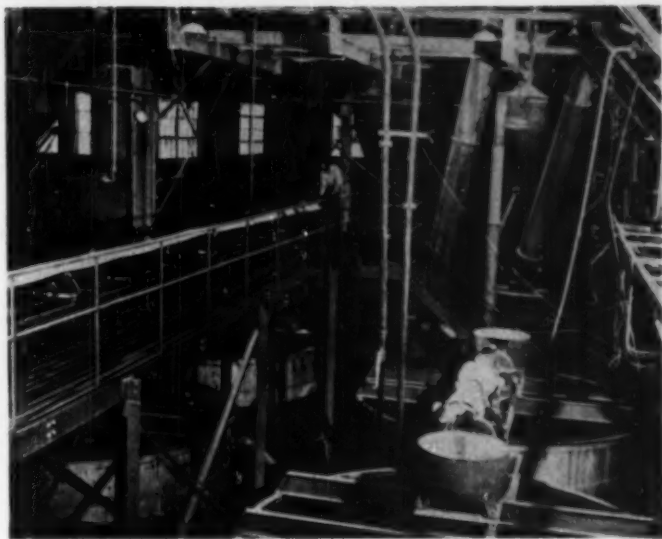
Reaction Tanks Equipped With Turbo-Agitators. International Minerals & Chem. Corp.

electrically driven auger bits. The holes are usually in vertical rows 4 ft. apart, each row containing 3, 4 or 5 holes depending on the height of face.

Blasting is done at the end of each shift at International. Primers are made up underground and powder and primers are hauled from underground magazines to the faces in insulated cars with insulated couplings. Powder consumption is 3 to 5 times that required for coal, averaging .75 lb./ton of ore. The shooting circuit is 200 v. a.c. taken off the transformer serving the section with power but through a separate blasting line having locked switch boxes.

Most of the loading is done with caterpillar-mounted conveyor-type loaders into shuttle cars which convey the

ore to the main track line where from a ramp or through an elevating conveyor it enters the mine cars. Shuttle cars may be either trolley or battery type. Double trolley cars of 11-ton capacity are used at International to make hauls up to 2500 ft. with little loss in loading efficiency.

Main line haulage is with trolley locomotives on rails. These locomotives range in weight up to 20 tons and can haul a substantial tonnage of ore in one train. The ore is carried to the foot of the shaft where the cars are dumped by a rotary dump. Uncoupling is unnecessary since the cars are equipped with swivel couplings.

Under the dump is a hopper and pan feeder which feeds a single roll tooth crusher. In passing through the crusher,

REFINED KCL PROCESS
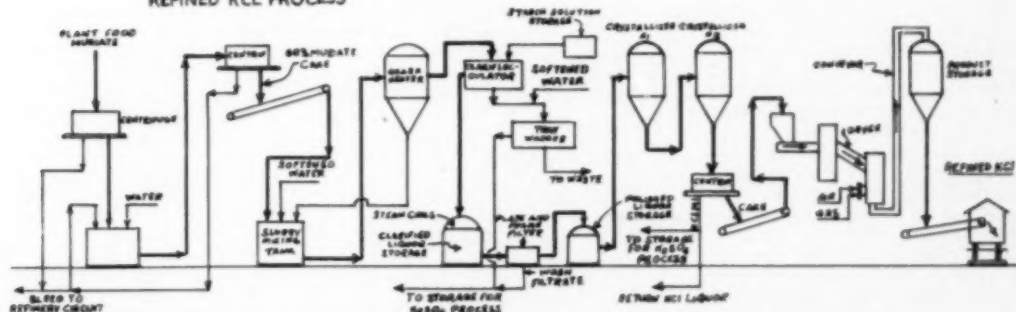
Flow Sheet of Potassium Chloride and Potassium Sulfate Process, Refined KCl, International Minerals & Chemical Corp.

```
MINE ORE
SYLVITE
   │
GRIZZLY
   │
CONE CRUSHER
   │
SCREENS ─────────► Mine Run Salt
   │                (Manure Salts)
HAMMER
MILL
   │
BALL
MILL
   │
SPIRAL CLASSIFIER
   │
FLOTATION CELLS ──────────── HEATING TANK
   │                              │
                              THICKENERS
DRAG CLASSIFIER                   │
   │                          FILTER
FILTER        COOLING            │
Standard      TANK
60% K₂O                      TAILINGS
PRODUCT                      NaCl
   THICKENER
        │
     FILTER
        │
FURNACE        CRYSTALLIZATION
   │               PLANT
CASTING        Chemical Grade
WHEEL
   │
COOLER
   │
Granular Grade
60% K₂O
PRODUCT
```
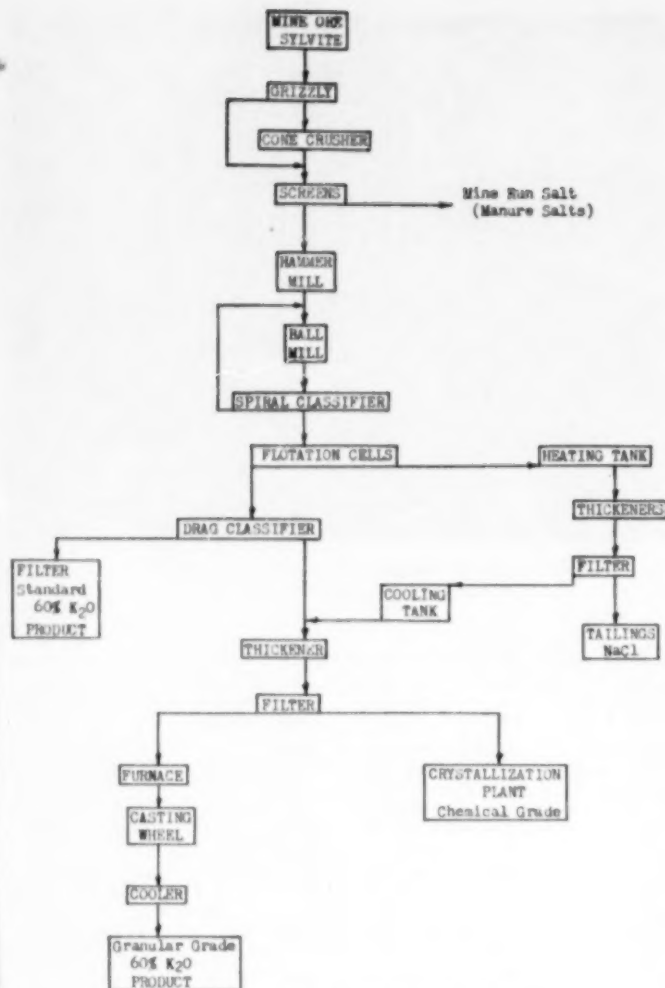
Fig. 2. Block Flow Diagram of Refinery. Potash Co. of America.

ore is reduced to 5 in. maximum size and falls into a skip pocket from which it is loaded into 5-ton capacity skips by automatic skip loaders for elevation to the surface. Two skips run in balance on the hoist and the hoisting-dumping cycle averages just more than a minute.

Transformers and generators for supplying power are located in underground substations. All ordinary repairs are performed in well-equipped shops carved out of the ore on the working level.

These operations are carried out under favorable conditions almost unbelievable to those familiar only with coal or hard-rock mining. The entire underground area is clean, dry, well ventilated and lighted. Ample headroom is provided for men and equipment. The temperature is relatively constant the year round at about 75° F. and the variable coloring and reflecting power of the ore make the workings a truly beautiful sight.

Refining

Although all three Carlsbad operations turn out similar end products from similar raw materials, the methods are distinctly different.

Refining-Sylvite. The oldest producer United States Potash Co., located its refinery on the Pecos River, some 13 miles west of its mine. At the mine site the ore is crushed and screened. A portion of one fraction is taken off for direct shipment to market as so-called manure salt. The remainder is split with one portion reserved for processing at the refinery and the other concentrated at the mine site. This concentration is an operation in which the ore is washed to remove slime, conditioned with reagents to offset the small difference in gravity between the potassium chloride and sodium chloride and then tabled. The lighter, reagentized potassium chloride moves across the table riffles, while the heavier sodium chloride is removed at the end of the table. The solid tails are separated from the brine in a drag classifier and sent to a tailings dump. The solid product averaging 50% K₂O (80% KCl) is likewise removed by a drag and then dried for final shipment. Brine from both classifiers is combined, clarified by thickening for mud removal and then returned to the head end of the process.

All three solid products, the manure salts, the 50% granular material and the largest portion, that designed for processing in the refinery, are carried to the refinery on a narrow gauge railroad owned by the company. At the refinery the granular and manure salts are stored for shipment to market. The remaining ore is subjected to a selective solution-crystallization process producing potassium chloride averaging about 99%.

Basis for the process is the difference in temperature-solubility relationship between the two main constituents of the ore potassium and sodium chlorides. In solutions saturated with both salts, the solubility of potassium chloride increases rapidly with the temperature while that of sodium chloride remains virtually constant. A cool solution saturated with both salts is heated in the condensing coils of the coolers and then further with exhaust steam from the power plant.

The hot brine, still nearly saturated in respect to sodium chloride and in the presence of potassium chloride, is fed into a continuous dissolving system, in which ore is carried countercurrent to the flow of hot brine. The potassium chloride and a small portion of the sodium chloride are dissolved, leaving the bulk of sodium chloride unaffected. The pulp is dewatered with classifier and continuous centrifugal equipment and the solid tails rejected. The hot brine is clarified to remove clays and slime in insulated heat-retaining thickener equipment, and the underflow clay is freed of residual potassium chloride by processing in countercurrent decantation units, after which the mud is discharged along with the salt tailings. The hot brine from the thickeners is pumped in a continuous flow through vacuum crystallizers. The potassium chloride, crystallized out in this step, is separated from the brine and dried on top feed rotary filters, and either loaded direct for shipment or sent to storage. The brine filtrate is reheated and returned to the head of the process as described previously.

The Potash Company of America was the first to apply a flotation process to the beneficiation of soluble potash salts on a commercial scale (*1*).

Its refining plant is located at the mine site. Ore from the mine is crushed to size and screened. As at the United States Potash Co., a portion of the screened material is shipped directly to market as manure salt. The remainder is further sized in a hammer mill and then pulped with brine and milled in a ball mill. The pulp is then classified in spiral classifiers, the underflow returned to the grinding circuit and the properly sized pulp reagentized for froth flotation. In the search for flotation agents, some were found excellently selective in respect to sodium chloride from a pulp containing the two salts and the Potash Company of America process was designed to take advantage of these developments. The reagentized pulp goes through a series of flotation cells in which air is introduced at the bottom in such a manner as to form a small bubble froth. This air may be from an outside source, from the agitators or both. The filmed sodium chloride particles are picked up and carried to the surface in the froth which is automatically and continuously scraped off. The underflow is classified and the sands are dewatered on vacuum filters and dried in rotary driers to produce standard 60% muriate. The classifiers overflow is thickened, the overflow brine returned to the circuit and the underflow filtered. The filter cake serves as feed for two proceses. In one, similar to flaking operations, the cake is melted in a reverboratory furnace and then flowed onto a large horizontal disc-type cooler from which it is continuously scraped in granular particles. The remainder of the cake is redissolved and recrystallized to produce a chemical grade of potassium chloride analyzing 99.9%. The regular and granular muriate products average about 97% potassium chloride.

Some potash is floated along with the salt. The tailings pulp is therefore heated slightly in tanks equipped with coils and agitators. Heat is supplied to the coils in hot water from the jackets of the diesels supplying power to the plant. The potash is dissolved, the pulp filtered and the solid salt sent to the dump. The brine is then cooled in tanks similar to those just described but with water from the cooling tower in the coils. The potash crystallizes out and is recovered in the thickener supplying feed to the granular and crystallizer steps.

International Minerals & Chemical Corp. markets no crushed ore as manure salts. In addition to 50% granular and 60% K_2O regular grade KCl it produces Sul-Po-Mag, potassium sulfate, and 99.9% chemical grade KCl. Sul-Po-Mag is a registered trade mark for the double salt potassium magnesium sulfate.

Langbeinite ore from the 800-ft. level and sylvinite from the 900-ft. level are brought to the surface on different schedules of the same hoist. Dumped into adjacent bins they are then kept separate in subsequent processing until a portion of each is used in the production of potassium sulfate.

The sylvinite ore is reduced in a circuit consisting of crushers, screens and hammer mills to produce a minus 6-mesh product
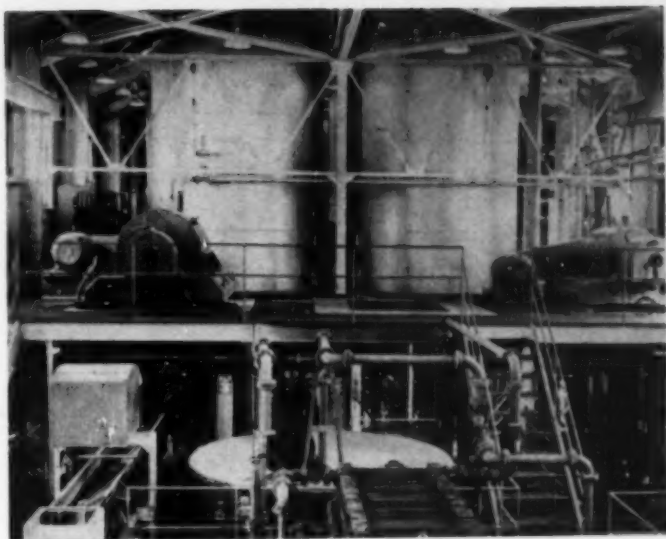
Bird Continuous Solid Bowl Centrifugals in Foreground and Vacuum Crystallizers in Background.

International Minerals & Chem. Corp.
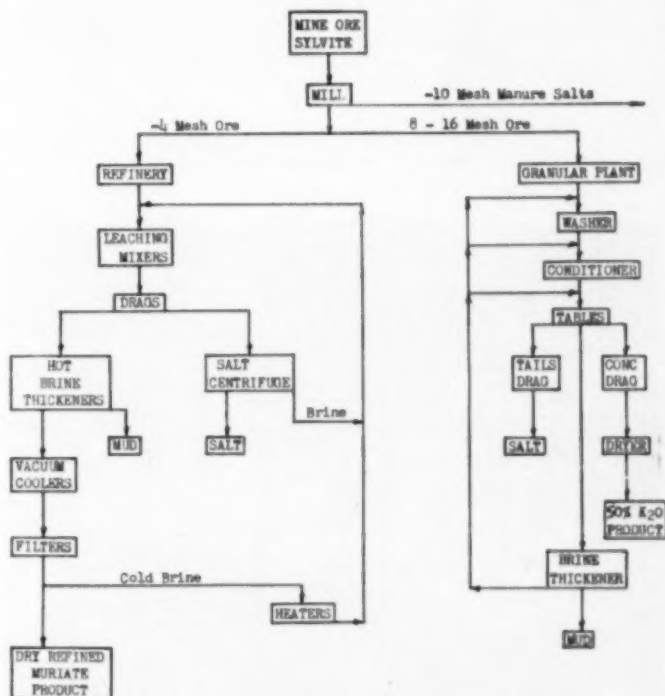
Fig. 3. Block Flow Diagram of Granular Plant and Refinery

U. S. Potash Co.
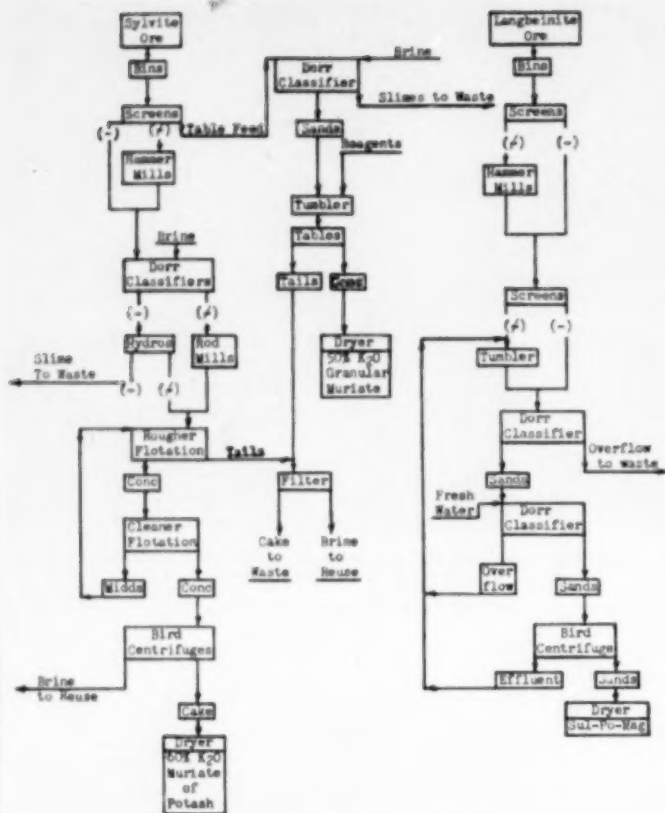
**Fig. 4. Block Flow Diagram of Refinery.
International Minerals & Chem. Corp.**

**Drilling Mine Face Using Jeffrey A-6 Post-Mounted Electric Drills.
International Minerals & Chem. Corp.**

which goes to the flotation section and an intermediate fraction which feeds the tables. This latter fraction is scalped out of the run of mine ore, thus relieving the crushing section of this tonnage. In both crushing circuits operating variables are controlled as well as possible to keep size limits at a minimum.

The table feed is pulped with saturated brine and deslimed in a rake classifier. The brine is returned to the main brine system for clarification and reuse. The deslimed feed is then reagentized in a rotary mixer and the sodium chloride and potassium chloride separated as described earlier in the discussion on the United States Potash Company methods. The granular concentrate is deliquored on a drag classifier, dried in a rotary drier and sent to storage. The product averages 50% K_2O and is produced primarily for direct application as a fertilizer where large particle size is desired. The table tails are dewatered in a centrifuge and sold for use as a stock salt.

The flotation feed is pulped with a potassium chloride-sodium chloride saturated brine and classified in two Dorr classifiers. The overflow is suitable for flotation after desliming which is accomplished in hydroseparators. The overflow of the hydroseparator is thickened, the slimes filtered and discarded and the clear brine returned to storage for reuse.

The rake discharge of the classifiers is reduced in rod mills and then joins the hydroseparator underflow as suitable flotation feed.

International developed its flotation process around reagents selected in respect to potassium chloride, which could then be floated free of the sodium chloride in the original ore. It has been established that the crystals of the two salts are reasonably well unlocked when crushed to 14 mesh; and the subsequent problem involves only separating the two distinct crystalline materials.

The flotation section is conventional in its general arrangement. However, the design of the equipment, the reagents used and the method of controlling operating variables represent several years' intensive development work by the company's metallurgists.

As a result, the plant successfully floats off approximately 98% of the sylvite content of the ore. This efficiency, applied to a process involving two materials so nearly alike physically as sodium chloride and potassium chloride, handling them in water, in which both are readily soluble, and separating them without recourse to solution methods is a respectable accomplishment.

The concentrate from the flotation cells is centrifuged, dried and sent to storage. The centrifuge filtrate is treated in thickeners to remove suspended solids and the brine sent to storage for reuse.

The flotation tails are likewise thickened, the underflow filtered to remove the sodium chloride which is discarded, and the overflow returned to the brine storage reservoir

together with the filtrate and thickener overflow from the potassium chloride dewatering step.

Refining—Langbeinite. The beneficiation of the langbeinite ore does not present a serious problem. International has been successful in the development of an efficient fresh-water washing process in which the chloride gangue salts are dissolved away to leave residual langbeinite. Although langbeinite is soluble, the rate at which it dissolves is low. This low rate, coupled with the relatively high rate for the gangue salts, furnishes the basis for the process.

Since langbeinite is a soluble salt, its extraction efficiency in a fresh-water washing process is a function of the rapidity with which the wash is accomplished. The salt content of the rejected wash water is also a function of processing time, and therefore optimum performance is obtained only after a delicate balance is reached between water consumption, equipment capacity, and extraction efficiency.

International utilizes a continuous countercurrent washing process which gives maximum solution of the gangue salts in minimum contact time.

Briefly the process consists of the following steps:

Mine run ore is dry-crushed by Jeffrey hammer mills operating in closed circuit with vibrating screens. The crushed ore is then screened to make a separation at 10 mesh. The plus 10-mesh material is sent to a washing tumbler where it is pulped with a portion of the wash water. The tumbler discharge is mixed with the minus 10-mesh fraction and the balance of the wash water and is pumped to the first of two Dorr classifiers operating in series. The feed water is added to the second classifier with the sands from the first unit. The overflow from the second classifier flows by gravity to the washing tumbler and then is pumped to the first classifier with the new feed. The overflow from this classifier is treated in a cyclone for removal of suspended fines and is rejected as waste. The liquor rejected from the section analyzes above 20% NaCl whereas the residual solid phase analyzes from 96 to 98% langbeinite. The solids are centrifuged and dried to become finished products.

Potassium Chloride and Potassium Sulfate. In addition to the metallurgical benefaction of potash ores, International produces a chemical grade potassium chloride having a minimum purity of 99.9+% KCl and an improved grade potassium sulfate analyzing 95% K_2SO_4 minimum.

Production of potash chemicals made directly or indirectly by the electrolysis of potassium chloride requires or at least benefits by high potassium chloride purity. The removal of impurities, particularly the metals, iron, calcium and magnesium and the sulfate radical which

have noticeable effect on efficiency, electrode life and product purity, has been made economically possible at Carlsbad by taking advantage of existing large tonnage operations producing muriate of potash (60% K_2O or 95% KCl) and integration with the production of sulfate of potash (52% K_2O or 95% K_2SO_4).

The process is simple both in concept and design, involving only a single recrystallization step utilizing as a raw material the high grade (60% K_2O or 95% KCl) muriate of potash and recycling approximately 90% of the soluble impurities contained in this raw material back to the refinery brine circuit. The balance of the impurities is eliminated by combining the potassium chloride process with a new process for the production of potassium sulfate.

This new potassium sulfate process uses the total potassium chloride mother liquor as raw material and is a modification of the previous sulfate process. The new process is more efficient, utilizes the same type of equipment and is ingeniously combined with the potassium chloride process to the benefit of both.

Potassium Chloride Process. The raw material (muriate of potash 60% K_2O) is cut from the refinery stream after it has been centrifuged but prior to drying. The solid muriate of potash is repulped with recycle brine to permit easy transfer to the chemical plant and to dissolve part of the soluble impurities. These are eliminated in the early stage of the process by continuously bleeding the repulp circuit into the main flotation plant brine circuit where the potash values in the bleed can be recovered.

The muriate is separated from the recycle

brine by a Bird continuous solid bowl centrifugal. The muriate cake is repulped in fresh water and solution is accomplished in an Ozark-Mahoning submerged combustion unit, the ratio of muriate to water being automatically controlled to produce a solution saturated at 4° C. below the heater operating temperature.

Following solution of the muriate the insoluble impurities are coagulated with starch in a Dorr Clariflocculator to produce a slime free overflow. The underflow is treated for maximum recovery of potassium chloride values in a Dorr three-compartment tray washer, the overflow containing the potassium chloride values being bypassed to the potassium sulfate process, the underflow is discarded.

Crystallization of approximately one-third of the potassium chloride in the liquor is effected by means of a two-stage vacuum crystallizer cooling the hot clarified liquor to 25° C. Vacuums of 2.5 in. Hg and 0.7 in. Hg are maintained by multistage steam jet ejectors, boosters, and barometric jet ejectors.

The potassium chloride crystals are separated from the mother liquor by a Bird continuous centrifugal and given a displacement water wash in the same operation. The centrifugal cake is dried to less than 0.1% moisture in a countercurrent dryer. The dried product is dispatched by air conveyor to the storage silo.

The potassium chloride mother liquor containing the balance of the soluble impurities plus wash water is transferred to the potassium sulfate process where full recovery is credited. This total bleed eliminates the possibility of product contamination through build-up of insoluble impurities.

The purity of the solid phase potassium chloride produced is, of course, dependent upon the concentration of impurities in the mother liquor and its effective separation and displacement wash in the final Bird centrifugal. This is particularly true of

Aerial View U. S. Potash Co. Refinery, Carlsbad, N. M.

both sodium and magnesium sulfate; however, sodium chloride is always present and the ratio of sodium chloride to potassium chloride is dependent upon the sodium chloride concentration of the process brines, approximately 25% of the sodium chloride contamination in the potassium chloride produced by International is attributed to this isomorphic crystallization. The presence of bromine is attributed also to this same phenomena here, however, isomorphic crystallization accounts for almost 100% of the bromine contamination. The only contaminating salt stable at low concentrations is synginite ($CaSO_4 \cdot K_2SO_4 \cdot H_2O$). This salt appears whenever the calcium concentration of the process liquors is allowed to increase.

Potassium Sulfate Process. This process involves the reaction of liquid and solid phases in the reciprocal salt pair system magnesium chloride, potassium sulfate water. The phase reactions are complicated and can be thoroughly understood only in the light of certain solubility data. Solubility data on this system have been obtained independently by D'Ans, Van't Hoff, and others, and check within reasonable limits.

On slurrying 60% muriate, ground langbeinite, mixed salts from the recovery operation, and water in the proper ratio, potassium sulfate crystallizes until leonite becomes stable. This phase reaction is represented by the following equations:

$$K_2SO_4 \cdot 2MgSO_4 + 4KCl \rightarrow$$
$$3K_2SO_4 + 2MgCl \quad (1)$$

$$K_2SO_4 \cdot MgSO_4 4H_2O + 2KCl \rightarrow$$
$$K_2SO_4 + MgCl_2 + 4H_2O \quad (2)$$

In order to crystallize the maximum quantity product per unit weight of water used, the liquor (potassium sulfate mother liquor) must be saturated with potassium chloride and leonite ($K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$).

After allowing sufficient time for the solution to approach equilibrium with the salts, leonite, potassium chloride and potassium sulfate, the product potassium sulfate is separated from the slurry, dried and stored.

The potassium sulfate mother liquor from the above operation is evaporated to a point where, on cooling to 30° C., the reject liquor is just saturated with sodium chloride.

When potassium sulfate mother liquor is evaporated, langbeinite (above 70° C.) and potassium chloride become stable. On cooling the evaporator product containing langbeinite and potassium chloride to 30° C., phase reactions occur, causing the langbeinite to convert to leonite. If sufficient water is evaporated, part or all of the langbeinite (again depending on degree of evaporation) will be converted to kainite ($KCl \cdot MgSO_4 3H_2O$). The possible phase reactions in this system are represented by the following equations:

$$2(K_2SO_4 \cdot 2MgSO_4) + 2KCl + 12H_2O \rightarrow$$
$$3K_2SO_4 MgSO_4 \cdot 4H_2O + MgCl_2 \quad (3)$$

$$K_2SO_4 \cdot 2MgSO_4 + KCl + 7H_2O \rightarrow$$
$$KCl \cdot MgSO_4 \cdot 3H_2O + K_2SO_4 \cdot MgSO_4 \cdot 4H_2O \quad (4)$$

$$K_2SO_4 \cdot 2MgSO_4 + KCl +$$
$$MgCl + 9H_2O \rightarrow 3KCl \cdot MgSO_4 \cdot 3H_2O \quad (5)$$

It is doubtful if the sodium chloride concentration of the mother liquor will be sufficiently low to permit evaporation to a point where reaction No. 5 will occur. The cooled slurry will contain leonite from reaction No. 3 and possibly kainite from reaction No. 4.

After the mother liquor has been evaporated and cooled, the mixed salts (predominantly potassium chloride with some leonite and possibly kainite) are separated from the liquor and recycled to the reaction step. These salts are suitable for the production of potassium sulfate.

The liquor from the above separation, containing the sodium chloride introduced as an impurity in the new feeds and the magnesium chloride formed in the reaction step, is rejected from the process.

Sodium chloride, present in the new feeds limits the process potassium recovery in the following manner:

1. The magnesium radical concentration at which potassium sulfate is stable is reduced by sodium chloride. The potassium recovery in the reaction step is therefore reduced.

2. The amount of water which can be evaporated in the recovery step is reduced by sodium chloride. Since the potassium recovery in this step depends on the quantity of water evaporated, the recovery of potassium as mixed salts is also reduced.

An increase of two moles of sodium chloride (60%) per 1000 moles of water reduces the process potassium recovery from 88.8% to 86.7%. The decrease in step recovery in both steps can result only in a reduced overall process potassium recovery. Therefore, the sodium chloride content of the new feeds (langbeinite and potassium chloride) must be controlled at the lowest practical minimum.

Reject liquor, introduced into the reaction step due to incomplete separation from the mixed salts lowers the reaction step potassium recovery. However, the over-all potassium recovery is not appreciably affected, since by increasing evaporation to compensate for the recycled reject liquor, the major proportion of the potassium values lost in the reaction step can be recovered in the evaporation-crystallization step.

In the production of potassium sulfate at International the raw materials; mother liquor from the potassium chloride process, langbeinite ($K_2SO_4 \cdot 2MgSO_4$) are reacted along with mixed salts (principally potassium chloride and leonite recovered in a subsequent evaporation-crystallization step) in four interconnected reaction tanks in or-

der to minimize short-circuiting and to provide necessary retention time for complete reaction. In order to keep the processing time within practical limits Raymond mills are used to reduce the langbeinite feed to 98%-200 mesh and all reaction tanks are equipped with Turbo-Agitators. For optimum recovery the quantities of raw materials are controlled so that the mother liquor, after reaction, is almost saturated with respect to potassium chloride and leonite.

Bird continuous centrifugals are used to separate the crystallized potassium sulfate from the mother liquor. The wet cake is dried and conveyed to storage.

The mother liquor nearly saturated with potassium sulfate, potassium chloride and leonite is concentrated by evaporating to approximately 67% of its original weight in three interconnected Ozark-Mahoning submerged combustion evaporators. Evaporation to the desired point, dependent upon the sodium chloride concentration of the mother liquor, is controlled by maintaining a constant boiling-point rise.

The hot slurry discharged from the evaporators is cooled to 30° C. in a two-stage vacuum crystallizer. Additional potassium chloride crystallizes, and langbeinite formed in the evaporation step, being unstable in the presence of potassium chloride below 63° C., reacts to form leonite.

$$2(K_2SO_2MgSO_4) + 2KCl + 12H_2O \rightarrow$$
$$3(K_2SO_4 \cdot MgSO_4 \cdot 4H_2O) + MgCl_2 \quad (6)$$

An Oliver rotary vacuum filter in closed circuit with a Dorr thickener is used for the separation of the solids from the discharged slurry. The solids from the filter (mixed salts) are conveyed by belt conveyor to the reaction step and the thickener overflow, a fairly concentrated magnesium chloride solution containing a small amount of the potash values in the feed, is rejected from the process.

This story of the potash industry vividly illustrates the rapid progress possible with the intelligent correlation and cooperation of scientific specialists. It is still going forward: Geologists and geophysicists are still improving methods for locating new sources of ore and more accurately estimating existing bodies. Mining engineers are constantly developing new machines and techniques for removal of ore from the earth. The metallurgists, the chemical engineers and the chemists are providing new equipment, new materials and new applications to continue this forward progress at a high rate.

Acknowledgment

CONDENSATION ON VERTICAL FINNED TUBES

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Heat-transfer coefficients for condensation of methanol and trichlor-ethylene have been measured by the Wilson method both using ⅝-in. diameter tubes with ¹⁄₁₆-in. high spiral fins, and using ¾-in. plain tubes in a vertical position. Tube lengths of 18 in., 36 in. and 48 in., and temperature differences of from 30° F. to 118° F. were employed. Results showed that the effects of fluid properties, tube length, and temperature difference were the same for the finned tubes as for the plain tubes. Consequently a Nusselt-type equation can be used for finned tubes with a coefficient of 0.725 instead of the 1.10 recommended for plain tubes. This reduction in coefficient per square foot of surface is more than offset by the increased area with the result that over-all coefficients for finned tubes are about 50% higher than for plain tubes. It is concluded that finned tubes may be used in vertical tube condensers with considerable economy in size of unit, or alternatively a gain in capacity.

THE high thermal resistance en-countered in the condensation of many nonaqueous fluids suggests the use of extended surfaces (i.e., fins) on the vapor side. Tubes with spiral fins on the outside have been used with success in horizontal tube condensers. Data (3) have been presented showing that condensing film coefficients for such tubes may be predicted with the usual Nusselt-type equation by use of an appropriate diameter factor. Finned tubes would also be expected to be of advantage in vertical tube condensers. However, use of tubes with spiral fins of low pitch does raise the question of possible blanketing of the fin area by the condensate. On the other hand, results gathered on horizontal tubes gave no evidence of loss of efficiency because of bridging of liquid between the fins even though such bridging was clearly visible.

The present work was undertaken to determine the effects of length, of temperature difference, and of fluid properties on the heat-transfer coefficients for condensation of vapors on the outside of vertical tubes with spiral fins.

Scope of Investigation

The usual equations for condensation of vapors on vertical tubes predict that

the coefficient should be a function of the thermal conductivity, latent heat of vaporization, density, and the viscosity of the condensate. In addition they predict that the coefficient shall be inversely proportional to the one-fourth power of the tube length and of the temperature difference across the film of condensate.

Variation in appropriate properties of the common nonaqueous materials is not great. Methanol and trichlorethylene were chosen as the fluids to use since their properties were such as to predict a ratio of coefficients of approximately 1.5:1 under similar conditions of length and temperature difference.

If the length and the temperature difference enter as the one-fourth power, considerable variation in these values is necessary to produce much change in the coefficient. Practical considerations dictated a range of length of from 18 in. to 48 in., a ratio sufficient to produce a 1.28 to 1 variation in predicted coefficient. The temperature difference used varied from a minimum of 30° F. to a maximum of 118° F., sufficient to give a 1.4 to 1 ratio of coefficients. Range of variables covered is given in Table 1. Thermal properties of the fluids used are given in Table 2.

The finned tubes used were of copper and all substantially of the same dimensions except for length. They had an integral fin with a pitch of about 1/16 in. The root diameter of the tube was about ⅝ in. In order that accurate comparisons could be made, data were

taken under the same range of conditions using plain copper tubes ¾ in. O.D. Some efforts were made to determine the effect of the use of a longitudinal groove on one side of the finned tube. It was thought such a groove might serve as a condensate drain to prevent blanketing of the lower portion of the tube. Since only a single type of groove was used, the data obtained are inconclusive but are included for their general interest.

Dimensions of all tubes tested are given in Table 3. General appearance may be seen in the photograph of Figure 1.

Theory

The nature of a finned tube precludes determination of condensing film coefficients by any of the procedures which involve direct measurement of tube surface temperature. The extrapolation method suggested by Wilson (16) is a convenient procedure and has been employed successfully before with finned tubes (3). For these reasons it was chosen here. The basic principle consists of making a series of measurements of over-all thermal resistance between the water on the inside of the tube and the condensing vapor at successively increasing water velocities. By appropriate plotting of the data, the results may be extrapolated to infinite water velocity at which point the total thermal resistance consists of the condensing film and the tube wall. The tube-wall resistance may be calculated from conduction theory and the condensing-film resistance determined by difference. Methods of calculation have been explained in detail in a number of publications (3, 7, 10, 14, 16).

It was pointed out in a previous publication (3) that the common conditions of condensation are not those specified for the usual interpretations of the Wilson-type plot. The principle requires that all coefficients (i.e., thermal resistances) be held constant except those on the water side. Since increasing water rate increases condensation rate,
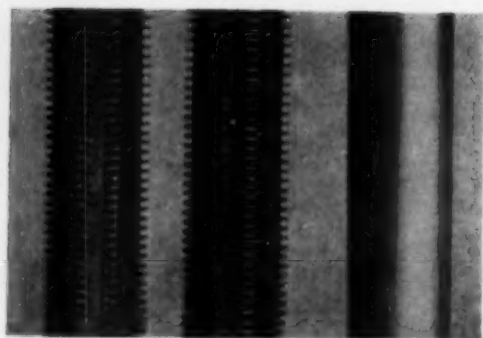
Fig. 1. Photograph Showing Typical Appearance of
Tubes Tested.
Tube at left shows longitudinal groove of
Tube 6, Table 3.
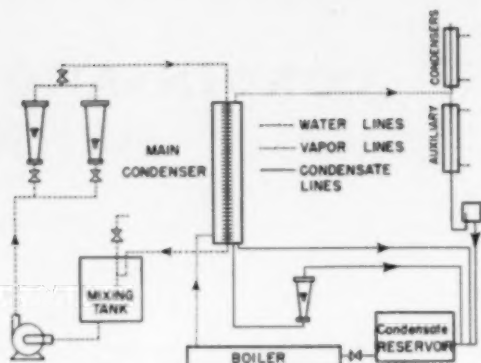
Fig. 2. Diagram of Condenser Setup.

other factors being equal, the condensing film coefficient does not remain constant. The result is that although the intercept of the plot is correctly stated as the resistance of the condensate film plus the tube wall, the slope of the line is not the constant of the water film coefficient equation. Indeed, it may be reasoned, and the data substantiate this, that the slope of the lines obtained when condensing on vertical tubes will vary with the over-all temperature difference.

Apparatus

The apparatus used in this investigation is shown diagrammatically in Figure 2 and a general view of the equipment is shown in the photograph in Figure 3. The condenser tube itself was placed vertically in the center of a standard 4-in. pyrex glass pipe. Vapor was admitted to the annular space between the tube and the glass pipe, while water was circulated through the tube. The vapor was generated in a horizontal tube boiler and entered the condensing section through a 4-in. glass tee at the bottom of the section. A perforated copper baffle plate was placed over the en-

trance and extended up the inside of the pipe to reduce impingement of vapor on the tube. Excess vapor was continuously purged from the top of the condensing section through two ½-in. copper lines to prevent any possible accumulation of non-condensables in the main chamber. These excess vapors were passed into an auxiliary condenser, the condensate from which could be continuously observed as a measure of the rate of purging.

Condensate from the principal condenser tube itself passed through a hole in the bottom tube sheet and through a calibrated rotameter. The metered condensate was returned to a storage reservoir and from there to the boiler. A cylindrical cup prevented condensate formed on the walls of the glass pipe from mixing with condensate formed on the condenser tube itself.

Water for the condenser was pumped from a 25-gal. open mixing tank through a calibrated rotameter down through the condenser tube and back to the mixing tank. Cold make-up water was added in the mixing tank and excess allowed to overflow continuously. Since rise in temperature through the tube was relatively small, this procedure permitted operation at any desired average water temperature.

Inlet and outlet water temperatures to the condenser tube were measured with calibrated mercury-in-glass thermometers 0-50° C. range with 0.1° C. graduations. The upper inlet thermometer was in a vertical position; the lower outlet thermometer was horizontal. Occasional checks made under conditions of no heat load showed a temperature difference error of less than 0.01° C. An air stream blowing across the emergent stems of the thermometers kept the difference in correction on the two thermometers to a minimum.

Vapor temperatures were taken with calibrated thermocouples to an estimated accuracy of the order of 0.02° F. Thermocouples junctions were placed in the vapor line to the condenser, and at 13-in. intervals in the vapor space in the condenser. Junctions were dipped in porcelain cement to prevent corrosion. A thermocouple was also located in the condensate return line to measure subcooling. Drierite tubes were attached to all open ends of the vapor side to prevent inspiration of water vapor from the atmosphere and thus cause dilution of the methanol or hydrolysis of the trichlorethylene.

TABLE 1—RANGE OF VARIABLES USED IN MEASUREMENT OF CONDENSATION COEFFICIENTS ON VERTICAL TUBES

Tube types:
Plain tubes, ⅝-in. O.D.
Finned tubes, ⅝ in. O.D. with 15 fins/in. 1/16 in. high.
Finned tube with longitudinal groove

Tube lengths:
18 in., 36 in., and 48 in.

Nusselt group for condensation:
2.64 × 10⁸ (with trichlorethylene) to
13.65 × 10⁸ (with methanol)

Over-all temperature difference:
30°, 53°, and 78° F. with methanol
70°, 93°, and 118° F. with trichlorethylene

Water rate:
4 ft./sec. to 19 ft./sec.

Reynold's number for condensate at bottom of tube:
230 to 3600 approximately

Tube position:
Vertical except for three series of runs on grooved finned tube at an angle of 45°

TABLE 2—PROPERTIES OF LIQUID METHANOL AND TRICHLORETHYLENE

t ° F.	k B.t.u. (hr.)(sq.ft.)(° F./ft.) (8)	ρ lb. cu.ft. (10, 12)	μ lb. (ft.)(hr.) (13)	C_p B.t.u. (lb.)(° F.) (14)	λ B.t.u. lb. (15)
		Methanol			
70	0.123	49.3	1.393	0.607	
90	0.120	48.5	1.210	0.615	
110	0.116	47.7	1.042	0.619	
130	0.112	47.0	0.904	0.621	
148	0.109	46.6	0.801	0.623	473
		Trichlorethylene (16)			
70	0.0800	91.7	1.39	0.228	
90	0.0770	90.2	1.26	0.230	
110	0.0745	89.0	1.15	0.232	
130	0.0720	88.0	1.06	0.234	
150	0.0690	86.8	0.980	0.236	
170	0.0665	85.5	0.908	0.238	
188	0.0640	84.3	0.847	0.242	101

During normal operation the apparatus was covered with glass wool insulation to aid in maintaining steady state over an extended period of time.

Experimental Procedure. The tube to be tested was carefully straightened, degreased, cleaned with dilute hydrochloric acid, washed, and thoroughly dried before installation. Installation was made through packing glands in the 1-in. thick bakelite tube sheets. Vertical positioning of the tube was checked by dropping a plumb bob through the tube. It was estimated that deviations from vertical were less than 0.2°. Water connections to the tube were made by sweating adapters and thermometer wells on the ends after installation in the condenser. Flexible metal hose connections to these adapters reduced strain and vibration on the tube to a negligible amount.

The finned tubes used had plain ends of outer diameter equal to the diameter over the fins. In setting these in the condenser, the condenser chamber length was adjusted so that only finned surface, and no part of the plain ends were exposed to the vapor. This was accomplished by use of a sealed-in, movable top tube sheet. The lower end of the tube was surrounded by a 3-in. diameter by 2-in. high cup which kept separate the condensate from the tube and condensate from the glass walls. By means of an adjustable standpipe outside the condenser, the level in this cup could be maintained constant under different condensate rates.

With the tube properly installed, condenser water was adjusted to the desired velocity and the boiler started, to send vapors into the system. After suitable adjustment of vapor rate and water temperature, the apparatus was allowed to purge for one and one-half hours during which time thermal equilibrium was established. Data were taken every 15 min. until calculations of three successive sets of data showed over-all coefficients constant within 1% based on rate of water flow and temperature rise. When a point had thus been established, the water velocity was changed and a new set of data determined. For each given set of conditions of fluid, tube size, and average water temperature, a series of seven runs was made at water velocities from 1800 to 8200 lb./hr. This corresponded to a range of linear water velocities of approximately 4 to 19 ft./sec. At the end of each series of runs, the first run was repeated to check on possible changes in the tube due to fouling or corrosion. In no case was any significant change observed.

As shown in Table 1, tests were made in this fashion for 4,3, and $1\frac{1}{2}$ ft. lengths of plain and finned tube, with methanol and with trichlorethylene. Average cooling water temperatures of 21°, 35°, and 48° C. were used. A 4-ft. length of finned tubing with a longitudinal groove on one side was used with trichlorethylene. The grooved tube was used in the vertical position and also at a 45° incline with grooved side down as shown in Figure 4.

Data and Calculations. Forty-two series of seven runs each were made to cover the various combinations of tubes, fluids and temperature differences. For each series a Wilson-type plot was made and a straight line passed through the data to extrapolate to infinite water velocity. Typical plots for finned and for plain tubes are shown in Figures 5 and 6. It will be noted that the abscissa scale is proportional to the reciprocal of the 0.8 power of the water

velocity and contains a temperature correction factor. This is based on the simplified Hinton-type (8) equation for the water film coefficient inside pipes.

A summary of the principal results is given in Table 4. In calculating the individual heat-transfer coefficient for condensation from the Wilson plot intercepts, the thermal resistance of the tube wall was calculated by the usual equations. For the finned tubes, fins were taken as 100% efficient, and only the resistance of the base tube considered. In all cases these corrections were almost negligible since the tube walls were copper and relatively thin.

The corresponding equation is

$$h_m = \frac{1}{A_o \left[1 - \frac{(D_o - D_i)}{(k_m)(\pi L)(D_o + D_i)} \right]}$$ (1)

The calculation of over-all heat-transfer coefficients, U, for use in the Wilson plots was based on the heat measured on the water side. The equation used was

$$\frac{1}{UA} = \frac{(t_v - t_w)}{W(t_{wo} - t_{wi})}$$ (2)

As a check, heat balances were made for a number of runs using the quantity of condensate. These values were consistently 4 to 8% below those based on water rates. It was felt that the difficulty of accurate measurement of the condensate together with doubt as to the value of the latent heats did not warrant their use.

Correlation and Discussion of Results. The theoretical equation developed by Nusselt (12) for condensation of vapors on vertical tubes takes the form

$$h_m = \beta \left(\frac{k^3 \rho^2 g \lambda}{\mu_f \Delta t L} \right)^{0.25}$$ (3)

The constant, β, is calculated as 0.943 using Nusselt's assumptions. However, the value of 1.13 has been recommended (9) based on average experimental data.

Results obtained in the present investigation are plotted on Figure 7 in a form designed to determine the constant

Fig. 3. General View of Apparatus.
Condenser section arranged for 18-in. tube is at left.

TABLE 3.—DIMENSIONS OF COPPER TUBES USED IN CONDENSATION EXPERIMENTS

Tube No.	Type	Length, L, ft. (nominal)	O.D.* D_o in.	I.D. D_i in.	Fins/in. N	Fin Height in.	Total Outside Area A sq.ft.*
1	Finned	4	0.635	0.550	14.79	0.056	1.640
2	Finned	4	0.632	0.550	14.79	0.060	1.912
3	Finned	3	0.633	0.550	14.98	0.057	1.400
4	Finned	1.5	0.634	0.550	14.81	0.057	0.687
5	Finned	1.5	0.634	0.550	14.86	0.056	0.674
6	Finned with groove †	4	0.635	0.550	14.79	0.056	1.689
A	Plain	4	0.750	0.670	.....	.....	0.785
B	Plain	3	0.750	0.670	.....	.....	0.589
C	Plain	1.5	0.750	0.670	.....	.....	0.294

* Diameter taken at base of fins for finned tubes.
† Groove runs length of tube. Groove width is 0.117 in. for top 16 in., 0.200 in. for center 16 in., and 0.284 in. for bottom $15\frac{1}{2}$ in. of tube length.
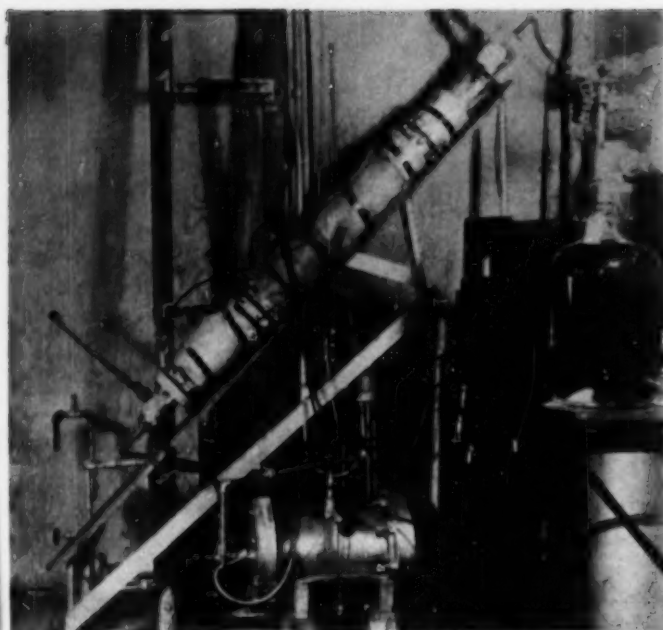
Fig. 4. View of Condenser Arrangement for Tube in Inclined Position.

TABLE 4—SUMMARY OF RESULTS

Series No	Tube No.	Vapor[1]	t ° F.	h_m B.t.u./(hr.) (sq.ft.)(° F.)	q/L at V = 15 ft./sec. B.t.u./(hr.)(ft.)
1	2	T	116.9	104	5280
2	3	T	116.8	119	5800
3a	4	T	116.9	109	5470
3b	5	T	116.3	126	6120
4	1	T	91.8	113	4190
5	3	T	92.1	122	4640
6a	4	T	93.1	127	4580
6b	5	T	93.0	155	5320
7	1	T	69.1	120	3170
8	3	T	68.3	120	3370
9	4	T	70.4	137	3550
10	A	T	114.0	149	3260
11	B	T	119.6	178	3910
12	C	T	118.9	207	4540
13	4	T	93.8	163	2780
14	B	T	92.7	191	3180
15	C	T	94.3	227	3880
16	A	T	68.7	175	2140
17	B	T	69.1	192	2420
18	C	T	68.0	237	2840
19	2	M	79.5	180	5860
20	3	M	79.3	209	6290
21	4	M	81.5	272	8420
22	1	M	52.6	202	4220
23	3	M	54.4	213	4550
24	4	M	53.8	317	5900
25	2	M	31.1	218	2610
26	1	M	27.8	236	2510
27	3	M	32.5	460	4190
28	A	M	79.0	269	3800
29	B	M	77.7	292	4640
30	C	M	79.6	372	5200
31	A	M	55.0	292	2870
32	B	M	50.9	324	2910
33	C	M	55.1	456	4140
34	A	M	31.1	345	1830
35	B	M	29.5	405	1920
36	C	M	33.3	463	2470
37	6	T	116.2	122	5260
38	6	T	93.1	124	4240
39	6	T	70.0	136	3430
40	6[2]	T	115.2	187 (est.)	7840
41	6[2]	T	90.8	237 (est.)	7380
42	6[2]	T	69.4	294 (est.)	7050

[1] T, trichlorethylene, b.p., 188° F.; M, methanol, b.p., 150° F.
[2] Tube inclined at 45° angle, groove down.

and the exponent for an equation of the form of Equation (3). Since the recommended value of 0.25 for the exponent appeared to be reasonable, lines having this slope were put through the data. The corresponding equations for these lines are

For plain tubes

$$h_m = 1.10 \left(\frac{k^3 \rho^2 {}_f g \lambda}{\mu_f L_s \Delta t} \right)^{0.25} \quad (4)$$

and for finned tubes

$$h_m = 0.725 \left(\frac{k^3 \rho^2 {}_f g \lambda}{\mu_f L_s \Delta t} \right)^{0.25} \quad (5)$$

An unusual feature of those correlations is the large range of independent variables covered. Cross-plots made of the effect of fluid properties, of tube length and of temperature difference each tend to justify the use of the exponent one quarter on the separate terms.

It is seen from Equation (4) that the data on plain tubes are in excellent agreement with the recommended equation (9).

The lower value for the coefficient obtained with finned tubes is to be expected and must be interpreted carefully. Under given conditions of the variables as set forth in Equations (3), (4), and (5), the finned tube carries more condensate load than a plain tube when compared at the same level from the top. Indeed, if coefficients for plain and finned tubes were identical, it would be expected that the value of L in Equation (3) would have to be replaced by an equivalent length when applied to finned tubes. This equivalent length would be the length of the plain tube which would have the same external surface as does the finned tube. For the tubes used here, this would amount to multiplying the actual length of finned tube by a factor of about 2.76. On this basis Equation (5) becomes

$$h_m = 0.933 \left(\frac{k^3 \rho^2 {}_f g \lambda}{\mu_f \Delta t L'} \right)^{0.25} \quad (6)$$

where

$$L' = \frac{A_o}{\pi D_o} \quad (7)$$

Equation (6) illustrates the point that the observed coefficients for this type of finned tube are only about 15% less than those which would be observed for a plain tube under similar condition of condensate loadings. This 15% reduction in coefficient per square foot of outside surface is easily offset by the more than 200% greater surface for the finned tube.

From a practical standpoint a more useful comparison between finned-tube and plain-tube performance is one made on a basis of equal lengths rather than on equal external areas. A heat-transfer

coefficient per unit length may be defined by Equation (8)

$$h_L = \frac{q}{L\Delta t} \quad (8)$$

The relationship between this and the more conventional value based on unit area is given by Equation (9)

$$h_L = \frac{A_a}{L} h_m \quad (9)$$

On this basis the equations for the heat-transfer coefficients may be written as follows:

For plain tubes 3/4-in. O.D.

$$h_L = 0.216 \left(\frac{k^3 \rho^2 g \lambda}{L \mu_f \Delta t} \right)^{0.25} \quad (10)$$

For finned tubes of the dimensions used in these experiments

$$h_L = 0.335 \left(\frac{k^3 \rho^2 g \lambda}{L \mu_f \Delta t} \right)^{0.25} \quad (11)$$

It should be noted that Equations (10) and (11) cannot be used except for the tube sizes indicated.

Practical comparison requires consideration of the over-all coefficients and not just the individual coefficients. Results on this basis are shown graphically in Figures 8 and 9. In these figures comparison is of values obtained at water velocities of 15 ft./sec. inside the tubes. This is higher than usual commercial velocities but similar results would have been obtained at other ranges. The choice of 3/4-in. O.D. plain tube to compare with the finned tube used was made because these would be the interchangeable sizes in a shell-and-tube unit. The finned tubes have an over-fin diameter of 3/4 in. and are provided with plain ends of this same outside diameter. Accordingly they may be slipped through 3/4-in. tube sheet holes and rolled in the usual manner.
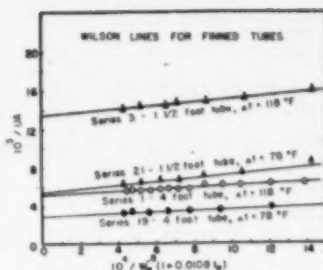
Fig. 5. Wilson-type Plots for Typical Data on Finned Tubes
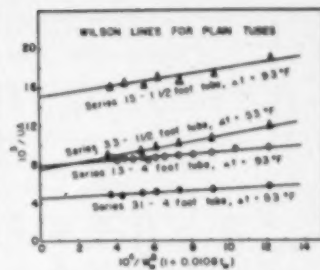
Fig. 6. Wilson-type Plots for Typical Data on Plain Tubes

Data for the grooved finned tube are also shown in Figure 10. It is seen that the values for the vertical position do not differ materially from those of finned tubes without a groove. In the inclined position, however, considerable improvement is noted. The principle behind the grooving was that by providing a channel for the run-off of condensate, the build-up of liquid layer on the lower section of the tube would be reduced. With the type of tube used, the fins are so nearly horizontal that very little spiral flow of condensate takes place. Inclining of the tube does permit draining of the space between fins. It is planned to make further tests using tubes having a multiple-spiral fin with greater inclination of the fin to the tube axis.

It should be pointed out that it is difficult to decide on a proper basis for comparison of the effectiveness of plain and finned tubes. The economic water velocity in finned tubes is usually greater on a linear basis than for plain tubes, but since fewer tubes are required may amount to a smaller total water consumption.

A general comparison can not be made of the results for vertical tubes with those reported by one of the authors for the same-type tube in a horizontal position because coefficients on vertical tubes depend on length. Comparison of predicted coefficients for a 4-ft. finned tube give values for vertical tubes of 24% of those for the same tube in a horizontal position. Comparison of the 4-ft. finned tube in a vertical position with a 4-ft., 3/4-in. diameter plain tube in a horizontal position shows values for the finned tube of 83% of those for the plain tube.

The equations given here for condensation coefficients for finned tubes are limited in their application to tubes having roughly the same fin type. That is, Equation (5) would be expected to hold for the tubes with 1/16-in. on a base tube from about 3/8-in. diameter up. The effect of more fins per unit length is open to question. It is anticipated this equation would give conservative values for tubes having fewer fins. In the absence of better information, the authors recommend Equation (6) for use with
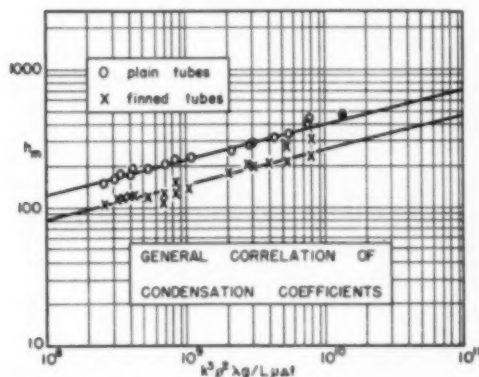
Fig. 7. Average Condensation Coefficients as Function of Nusselt's Number.
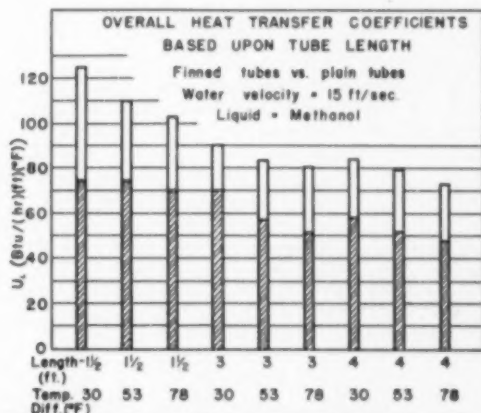
Fig. 8. Comparison of Over-all Heat-Transfer Rates for Finned and Plain Tubes in a Vertical Position. Total height of bar is for finned tube, shaded height for plain tube.
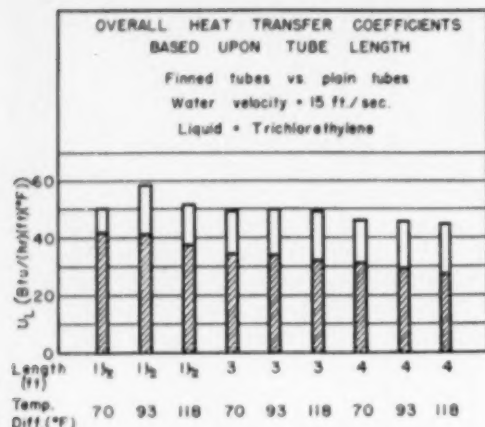
Fig. 9. Comparison of Over-all Heat-Transfer Rates for
Finned and Plain Tubes in a Vertical Position.
Total height of bar is for finned tube, shaded height
for plain tube.
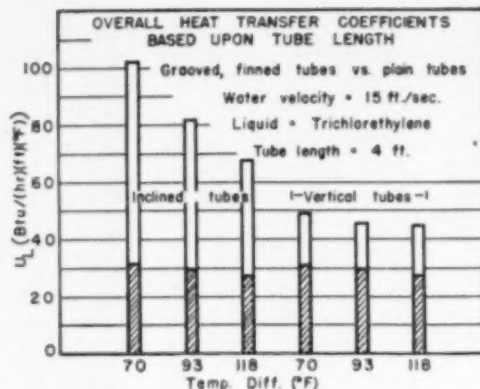
Fig. 10. Comparison of Over-all Heat-Transfer Rates for
Grooved Tube Vertical and Inclined with Those
for a Vertical Plain Tube.
Total height of bar is for finned tube, shaded
height for plain tube.

finned tubes with slight modifications of
fin number or fin height.

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Notation

A_o = total external area including
fins, sq.ft.

D_i = inside diameter of tube, ft.

D_o = outside diameter of tube, taken
at base of fins for finned
tubes, ft.

g = universal gravitational constant

h_L = heat-transfer coefficient per
unit length, B.t.u./(hr.)
(° F.)(ft.)

h_m = heat-transfer coefficient per
unit area, B.t.u./(hr.)(° F.)
(sq.ft.)

I = intercept on Wilson plot,(° F.)
(hr.)/(B.t.u.)

k_f = thermal conductivity of con-
densate, B.t.u./(hr.) (° F./
ft.)(sq.ft.)

k_m = thermal conductivity of tube
wall, B.t.u./(hr.)(° F./ft.)
(sq.ft.)

L = length of tube, ft.

L' = equivalent length of finned
tube, ft.

t_c = temperature of condensing va-
por, ° F.

t_w = mean temperature of water in
tube, ° F.

t_{wi} = inlet temperature of water in
tube, ° F.

t_{wo} = outlet temperature of water in
tube, ° F.

U = over-all heat-transfer coeffi-
cient, B.t.u./(hr.) (° F.)
(sq.ft.)

U_L = over-all heat-transfer coeffi-
cient per unit length, B.t.u./
(hr.)(° F.)(ft.)

V = water velocity, ft./sec.

W = water velocity, lb./hr.

Δt = over-all temperature difference,
° F.

β = a constant

μ_f = viscosity of condensate, lb./
(hr.)(ft.)

ρ_f = density of condensate, lb./cu.ft.

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Discussion

A. C. Mueller (Du Pont Co., Wil-
mington, Del.) : In a specific experiment
attempting to increase the rate of con-
densation of steam, we compared this
same type of fin tube with a plain tube.
With vertical tubes 16 to 20 ft. long we
observed no advantage with the fin tube.
We attributed this lack of benefit to
complete covering of the fins with con-
densate, since it was observed that con-
densate ran down over the tops of the
fins with relatively stagnant pools be-
tween the fins. You might have run into
this same effect if you had employed
tubes longer than 4 ft.

K. O. Beatty: The effect you point
out was anticipated as a possibility.
However our experiments showed that
even though the condensate appeared to
be running over the tops of the fins,
rates of heat transfer appreciably higher
than those for plain tubes were ob-
served. The three lengths of tubes used
showed no effect of length other than
the normal decrease, i.e., coefficients in-
versely proportional to the reciprocal of
the length to the one-fourth power. Al-
though the effect of increased length
should be watched with care, I do not
anticipate the results you have observed.

Your observations were made using
steam which frequently shows anomal-
ous behavior in condensation. We did
observe that accidental contamination of
trichloroethylene with water materially
reduced condensation rates. Droplets of
water could be seen hanging between
the fins and apparently blanketed them
off to a much greater extent than the
trichlorethylene itself did.

*(Presented at Forty-second Annual
Meeting, Pittsburgh, Pa.)*

EQUIPMENT FOR GENERATING ULTRA-SONIC ENERGY

BASIC DESIGN CONSIDERATIONS

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This paper considers sound and ultrasonic power in air, then some of the characteristics of the electrodynamic generator. This is followed by a more serious discussion on wave length, pressure, velocity, and energy relations in other media. Finally, magnetostrictive and piezoelectric generators are discussed briefly.

DURING the past few years, the public has become more keenly aware of what appears to be a new and fascinating type of energy linked with a modern name called "Ultrasonics." The term ultrasonics is applied to a field concerned with vibratory motions at frequencies exceeding that of the limit of hearing (18,000 cycles/sec.) and extending into millions of cycles per second. Industrial laboratories, research workers, and process industries are studying the applications of ultrasonics to their processes.

There is a need for a better understanding of methods of generating sonic and ultrasonic power. Design considerations of generators when applied to process media are equally important. The basic relations between forces, velocities, power, and energy when applied to well-known mechanical, electrical, and acoustical systems, can help promote an understanding of energy radiation at sonic and ultrasonic frequencies.

Sound and Ultrasonic Energy in Air. Sound in air is a familiar phenomenon. Not many realize the amount of power that may be required to provide the intensities of the familiar steamboat whistle or ordinary conversation. Sound engineers have established a standard sound level reference expressed in decibels. The reference level, zero decibels, is just above the sound produced by the random thermal vibrations of air molecules. Ordinary conversation, at 60 db., is a million times more intense. Painful sound, at 130 db., is ten million times as intense as ordinary conversation, but this intensity of painful sound is only about .0065 watts/sq.in. A whistle, capable of producing .0065 watts/sq.in. at a distance of 5 ft. from the source in a free field, must provide 300 watts of sound power since there are approximately 45,000 sq.in. of area in a sphere of 5 ft.

radius. Figure 1 shows the relationship between intensity, pressure, and velocity of such wave energy in air. If the generation of such power in the ultrasonic region is considered it must be remembered that wave lengths become shorter as the frequency is increased. Figure 2 shows the relationship between wavelength and frequency in air. Since whistles are resonators, dimensions of which are small compared with a wave length of the sound which they produce, such sources must necessarily become smaller and smaller in size as the generated frequency is increased. Production of high intensity energy is physically limited by the amount of pressure fluctuation that can be produced at the source.

The Hartmann air jet whistle (Fig. 3) is limited in power output by such pressure fluctuation. A high pressure air stream is blown directly into a cavity. By this means, frequencies up to 100 kc./sec. may be produced. At the lower ultrasonic frequencies up to 30 watts can be generated with an efficiency of about 20 per cent. Figure 4 shows the Hartmann whistle mounted near the focal point of a reflector. The intense 20-kc. sound wave is focussed upon the glass beaker and the resultant standing wave
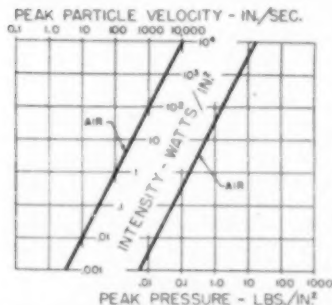
Fig. 1. Relationship between pressure, velocity, and intensity in freely traveling waves in air; also between maximum pressure and maximum velocity in standing waves and resonators.
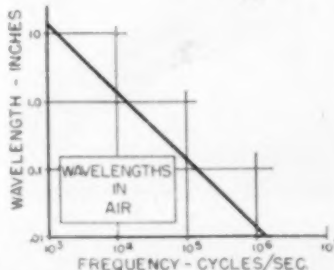
Fig. 2. Relationship Between Wave Length and Frequency in Air.
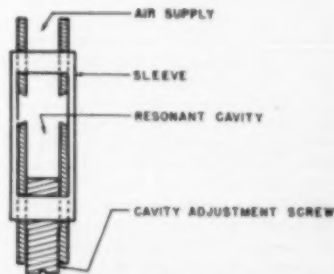
Fig. 3. Cross Section of Hartmann Air Jet Whistle.

pattern is recorded by the powder on the table.

Whenever two sound waves of the same frequency are traveling in opposite directions, standing waves are produced. In Figure 5, the same whistle and reflector are focussing the energy upon a steel block. The incident sound energy is reflected from the block and again a standing wave pattern is produced. Bits of cork are mysteriously held in air at intervals of ½ wave length. High intensities at some distance from the source are produced only as a result of concentration of energy by the reflector. Where larger amounts of power are required, a number of whistles must be operated in parallel. Synchronous operation of such sources is difficult. A siren conveniently produces multiple synchronous sources by chopping high pressure air. To do this, a disc having many small holes regularly arranged about its periphery is revolved at high speed in front of a high pressure air supply so that the air stream is pulsed by the holes in the disc. The frequency of pulsation is determined by the number of holes or apertures in the disc and by the speed of rotation. At 20,000 rev./min. 200 holes would produce a frequency of 100,000 cycles. Power outputs of many thousands of watts have been reported using this type of generator.

Electromagnetic Generators. Many are familiar with another type of sound generator—the loud speaker in radios. In this case, a coil of wire is supported on a cone in an electromagnetic field. The current in this coil produces a force which causes the cone to be displaced back and forth at the driven frequency. A similar device, designed for applications in industry, is called the vibration motor (*See* Fig. 6). Such a motor is particularly suitable for calibrating instruments of a wide frequency range. At the extremely high frequencies, a serious limitation is imposed upon this unit. The cone is essentially a moving mass; when such a mass is moved back and forth at a constant velocity at an ever-increasing frequency the displacement is continually decreasing while the acceleration is ever increasing proportional to frequency. Figure 7 shows this relationship between frequency, displacement, velocity, and acceleration. It may be seen from this chart that at ultrasonic frequencies the acceleration force may be thousands or even hundreds of thousands of times greater than the effective weight of the moving mass. In the vibration motor, these forces must be furnished by the current in the moving coil. This current must be supplied by an oscillator which can be operated with an efficiency of only 60 to 70 per

Fig. 4. Hartmann whistle mounted near focal point of parabolic reflector being used to produce standing wave patterns in powder.

cent at best. No real mechanical power output has been produced. It is for this reason that in most electrically driven high power generators mechanical resonance is employed. The electrical system now needs only to supply the losses. Forces previously required to move the mass back and forth are now supplied by the mechanical system. When the energy losses of such a system are small compared with the kinetic energy of the moving mass an extremely sharp resonance is obtained, and high stresses are produced with the material. Systems of this type are used in industry to determine the fatigue strength of
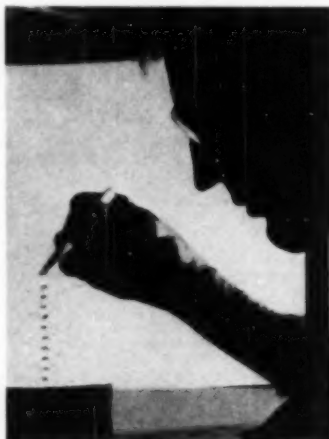
Fig. 5. Sound energy reflected down from a Hartmann whistle by means of parabolic reflector supports bits of cork in the standing wave pattern produced when the sound is reflected from the steel block.

material. They may be magnetically or acoustically driven. If application of such mechanically resonant systems to ultrasonic frequencies are considered it is found again that just as in whistles the physical dimensions of the resonant unit must be small compared with a wave length of the vibration within the material. Thus such generators are primarily limited to the audio frequencies.

Wave Length, Pressure, Velocity, and Power Relations in Materials Other Than Air. So far air as a medium for the transmission of sonic and ultrasonic power has been under consideration. This type of power may be transmitted in all materials. But what of the wave length in some of these materials? Figure 8 includes air, water, quartz, barium titanate, nickel and steel. Nickel is a magnetostrictive material; quartz and barium titanate are piezoelectric materials suitable for the generation of mechanical energy by electrical means. It is noted that for any particular frequency, wave lengths in water are longer than in air, and in steel they are still longer.

The relation is important since this determines the basic dimensions of resonant generators at ultrasonic frequencies. First mode thickness resonance of plates or longitudinal resonance of rods occurs when these dimensions are ½ wave length. Wave lengths are also important when use of standing waves is considered in process media to produce the necessary pressure and velocity fluctuations at ultrasonic frequencies. In such applications, the generator need only supply the power losses in the medium. The required power may be applied at high pressure or at high velocity depending upon the configuration of the standing wave system.

The product of force and velocity has dimensional units of mechanical power and may, therefore, be expressed in watts.

This relation between force, velocity, and mechanical power is similar to the relation between volts, amperes, and electric watts of a 60-cycle power system. When the voltage and current are in phase the product of volts and amperes determines the amount of power in watts. This electric power may be utilized in the form of heat or in the form of mechanical power output from a motor. If the current and voltage are not in phase (90° out of phase) there is only a reactive power or circulating component which will not register any real power consumption.

In a mechanical system when the forces and velocities are in phase, maximum power is produced. In a traveling wave in any medium the forces and velocities peak simultaneously, and may
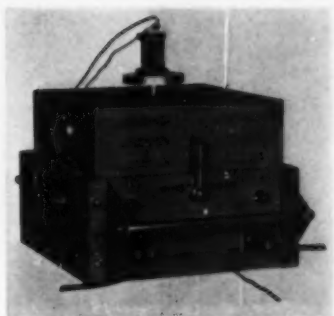
Fig. 6. Electrodynamic Vibration Motor for Industrial Purposes.

therefore be considered to be in phase. Figure 9 shows the relation between pressure, velocity, and intensity in materials. Since pressure is force per unit area, the product of pressure and velocity can be expressed as power per unit area.

It is observed that traveling waves in water and steel require a much greater pressure and a correspondingly lesser velocity than in air to produce a chosen intensity. Also it is noted that in a resonant plate or a standing wave the ratio of maximum velocity at one point to the maximum pressure at the other point is the same as for a traveling wave. This appears more logical when one remembers that a standing wave may be considered to consist of two waves traveling in opposite directions. A resonant plate may be considered a $\frac{1}{2}$ wavelength section of a standing wave.

Referring to Figure 9 again, if one wishes to produce 10 watts/sq.in. of radiated power in water using a $\frac{1}{2}$ wave-length quartz plate resonating in thickness, 30 lb./sq.in. pressure must be produced at a velocity of 5 in./sec. The quartz face must necessarily vibrate at this same velocity, 5 in./sec. The stresses or pressure at the center of the

quartz plate will be (from Fig. 9), approximately 300 lb./sq.in.

Electric equivalent circuits may be devised for ultrasonic generators driving any medium. These circuits aid materially in the proper application of generators.

The electronic circuit engineer is well equipped to handle such problems once he appreciates the similarity of these mechanical systems to his circuits.

Magnetostriction Generators. When a nickel tube is placed in an axial magnetic field, a change in its length occurs. When a variation in this field is produced by passing a current through a coil surrounding this tube at the resonant frequency of the tube, large stress variations are produced at the center with corresponding velocities at the ends. Such a tube, however, must be slotted, in order that the induced currents in the circumferential dimensions will not produce excessive electrical losses. Laminated sheets properly bonded in order to obtain low mechanical losses have been produced in recent years.

When the mechanical and magnetic structure is carefully designed for its application, large amounts of power may be produced, at reasonable efficiencies. In assemblies requiring large cross-sectional areas, a number of individual units are usually operated in parallel, actuating a common diaphragm or a thin plate. This plate is exposed then to the medium to be treated. Artificial cooling is generally required for magnetostriction generators when continuous operation at high power levels is essential.

The ability of nickel to withstand reasonable temperatures and extremely high stresses adds greatly to the attractiveness of magnetostriction generators at the lower ultrasonic frequencies. These generators become somewhat more difficult to construct at frequencies above 100,000 cps. It is known that
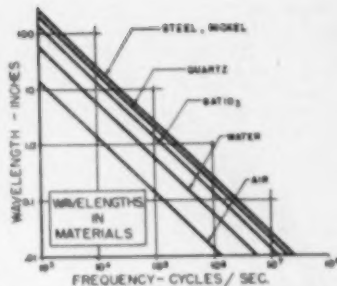
Fig. 8. Relationships Between Wave Length and Frequency in Various Media.

these generators must become smaller as the frequency of operation is increased, and multiple unit assemblies become more essential in order to expose a reasonable area for power transmission. Manufacturing costs are increased and piezoelectric materials become more suitable and economical.

Piezoelectric Generators. A voltage stress properly applied to any piezoelectric material will produce a change in its dimensions. When an a.c. voltage is applied at the resonant frequency of a properly designed piezoelectric generator, the voltage stress will be proportional to the forces required to supply the mechanical losses and the radiated power. A current must be supplied also which is proportional to the velocity of the ends of the resonator. To this must be added an out-of-phase current component due to the capacitance between the electrodes. The total current is the vector sum of these two currents.

Figure 10 is a photograph of various piezoelectric materials.

Rochelle Salts and Ammonium Di-Hydrogen Phosphates are extensively used in underwater sound devices. Both materials are water soluble and Rochelle salt is hygroscopic; hence, they are usually sealed in oil. Rochelle salt melts at 55° C. and ammonium dihydrogen phosphates become electrically conductive above 100° C.

When used under continuous operation, as high power ultrasonic generators in liquids at room temperature, Rochelle salt is limited by surface temperature rise which melts the crystals. Power outputs of approximately 3 watts/sq.in. may be obtained. Ammonium dihydrogen phosphates appear to fail under similar conditions at power levels of approximately 30 watts/sq.in.

Quartz has been for many years a favorite for high intensity ultrasonic work. A properly constructed disc prob-
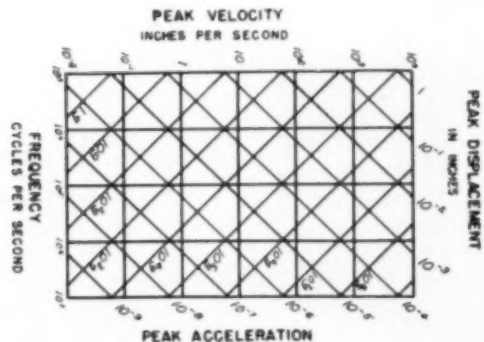
Fig. 7. Relationships between Frequency, Displacement, Velocity and Acceleration.

PEAK PARTICLE VELOCITY - IN/SEC

PEAK PRESSURE-LBS/IN²
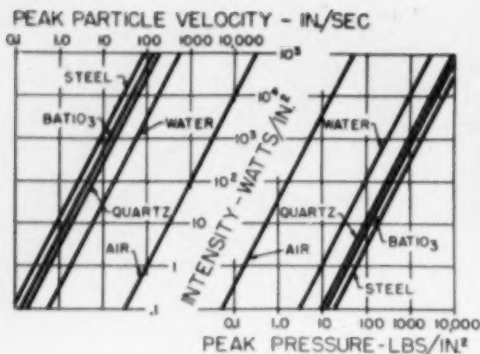
Fig. 9. Relationships between pressure, velocity, and intensity in freely traveling waves; also between maximum pressure and maximum velocity in standing waves and resonators.

Fig. 12. G. E. Ultrasonic Generator for Laboratory Work.

ably will support a vibrational stress of 5000 lb./sq.in. It will withstand high temperatures if temperature gradients are minimized. In its application to generators for liquids its power output is limited practically by the voltage stress that can be obtained without producing external arcing. Figure 11 is a photograph of a quartz generator. The edges of the crystal are surrounded by oil to prevent arcing around the crystal. Rubber rings producing a seal for the oil chamber are effective low loss mountings.

Figure 12 shows a complete ultrasonic generator suitable for laboratory work. Crystals for 300, 500, 750, and 1,000 kc. are readily mounted, and suitable coils are plugged in. To the crystal 250 watts is applied at a voltage up to 20,000 volts.

Barium Titanate Compound, a new material, basically a ceramic, has been developed in recent years as a result of the search for high dielectric constant ceramic materials suitable for capacitor applications. The titanates exhibit rather unusual characteristics in that they can be processed so as to possess desirable piezoelectric properties, and produce a high amount of power at relatively low

voltages. For example, where quartz may be limited by the voltage which can be applied, a barium titanate transducer with similar dimensions and frequency characteristics would produce the same amount of power output at a voltage of approximately 1/70 of that required for quartz. The most important consideration in the application of barium titanate compounds as an ultrasonic generator is that the operating temperature of the material is limited to approximately 100° C. At a temperature somewhat above this level the material would completely lose its piezoelectric properties and would have to be reprocessed in order to regain them.

Transducers of barium titanate have been built to deliver ultrasonic power at frequencies above 5 megacycles/sec. Since high power output can be obtained at these frequencies for a relatively low applied voltage, it follows that the electrical impedance of such a unit is low. For that reason these high frequency ceramic transducers can be operated directly in ordinary tap water with uninsulated leads as shown in Figure 13. This generator is operating at a frequency of 2½ megacycles/sec. An input of 300 watts is applied. A curved disc is radiating from both faces and is ar-

ranged to focus the energy from the concave face in the direction of the spout of water. Tensile strength tests of this material indicate that it should be able to support on the order of 10,000 lb./sq.in. The importance of this ceramic material to high power generators is obvious when it is considered that these pieces may be molded or extruded into any desired shape and that they may be processed to have good piezoelectric properties in any desired direction. Figure 14 shows some typical sizes and shapes that may be produced using a barium titanate ceramic as a transducer material.

Conclusions

In the application of high power ultrasonics to process industries, high fre-
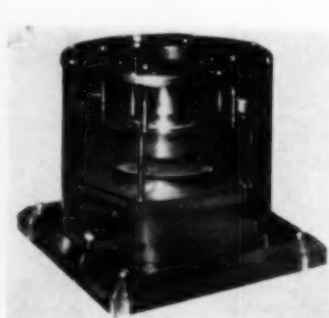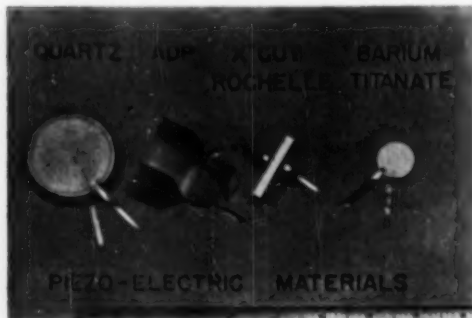
Fig. 10. Left: Piezoelectric Materials.

Fig. 11. Right: Quartz Transducer for G. E. Ultrasonic Generator.
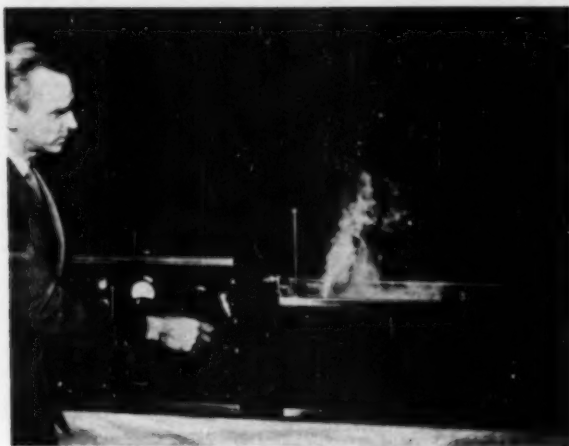
Fig. 13. Fountain of water and fog produced by small disc of uninsulated ceramic producing high intensity ultrasonics at 2½ megacycles/sec.
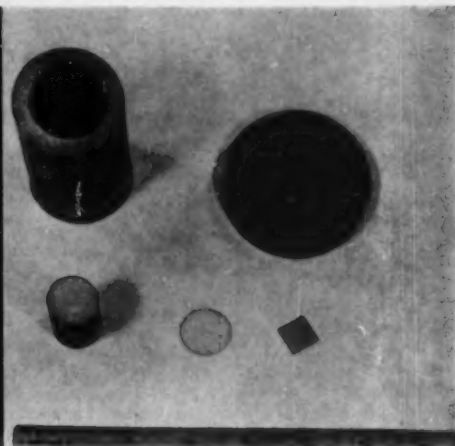
Fig. 14. Typical Sizes and Shapes of Ceramic Transducer Elements Made of a Barium Titanate Compound.

quency electric power supplies capable of delivering large amounts of power can be designed. Experience in induction heating and radio broadcast design makes this possible. High power radiators capable of converting electric power to mechanical power of the same frequency can be economically produced. The energy conversion can be accomplished with a high degree of efficiency when careful consideration is given to the basic relations between generators and the medium.

The cooperative efforts of research workers, process engineers, and generating-equipment designers must be concentrated on worth-while applications of ultrasonics. This will lead the development along a safe and certain road to the production of improved materials for more people at less cost.

Acknowledgments

Discussion

F. D. Mayfield (Celanese Corp. of America, Bishop, Tex.): What process economically would you use in the breaking up of foam?

W. H. Janssen: First, let us know the quality and density of the foam. Do you mean a precipitate of finely divided particles in a liquid? An emulsion? I would say for a foam, such as soap suds, the best process would be the use of air.

F. D. Mayfield: I am referring to a light foam on the surface of a liquid.

W. H. Janssen: Maybe Danser would like to answer that one.

H. W. Danser: (Ultrasonic Corp., Cambridge, Mass.): We are working on that now. I would like to say you would want to use gas phase sound generators.

F. D. Mayfield: Can you successfully precipitate finely divided solid particles in a liquid phase?

H. W. Danser: We haven't done much work in that field, but you can produce emulsions, which we have done, and you can precipitate fine solid particles from liquids. I would rather not attempt to give you an expert opinion. Is there anyone here who feels qualified to answer this?

Dudley Thompson (Virginia Polytechnic Inst., Blacksburg, Va.): I have done some work along this line and have found that four different phenomena are produced at low intensities in liquid systems at the same frequency. The order in which these phenomena occur with increasing intensity under these conditions are: (1) orientation, (2) movement, (3) accumulation, and (4) coagulation of the suspended particles. These occur below a power density of approximately 10 watts/sq.cm.; above this value disruptive forces come into play and dispersion and emulsification result.

Low intensity ultrasonic waves can materially facilitate coagulation in systems in which this phenomenon will take place.

H. V. Hess (The Texas Co., Beacon, N. Y.): How do power outputs for quartz and barium titanate compare when used in a gas rather than in a liquid?

W. H. Janssen: The power outputs of either quartz or barium titanate are materially reduced in a gas as compared to a liquid since the amplitudes of vibration must necessarily be much larger to obtain the same power output.

In a gas, however, the power output of quartz is limited no longer by arcing around the crystal but by the mechanical breaking point. Assuming that the barium titanate is pulsed or artificially cooled to compensate for heating caused by electrical and mechanical losses, the maximum power output of barium titanate is also determined by the mechanical breaking point.

Then under these conditions the maximum permissible stress in either material, coupled with its density and thickness for any given frequency determine the final amplitude limitation.

If we assume that barium titanate will support a vibrational stress twice as large as will quartz, the thickness of barium titanate is 82.4% that of quartz, and the density of barium titanate is 207.5% that of quartz, then barium titanate will produce approximately 37% more power than quartz.

(Presented at Thirteenth Regional Meeting, Houston, Tex.)

ORGANIZATION OF CHEMICAL
ENGINEERING PROJECTS

RICHARD MORTON

Chemical Engineer, New York

This paper attempts to contribute to the administrative phase of chemical engineering by discussing the various items entering into the execution of a chemical engineering project. The stepwise procedure is described which is necessary to carry a project from its inception to the completion stage and a recommended form of an engineering organization is outlined with which to accomplish this purpose.

MUCH has been written on the general subject of chemical engineering plant design including a book by Vilbrandt (*12*) with a voluminous compilation of references. He discusses the various factors entering into plant design, the selection of process equipment, and includes an organization check plan to ensure that all items entering into the plant design have been considered. General principles of chemical plant design have previously been discussed (*1*), while the organization of a chemical engineering pilot plant has recently been described (*4*). Tyler (*11*) outlines the forms of organization required to handle the administration, production, research, and sales departments of a chemical engineering concern. Genereaux (*10*) gives the following sequence for the design of a chemical plant:

1. The idea
2. Process development
3. Preliminary design
4. Estimating
5. Final design

It is the purpose of this article to discuss the above steps in greater detail and to recommend an organizational structure and procedure. The organization and procedures which will be described here are intended to apply to a large-scale project such as a petroleum refinery; however, the methods given will be equally valid for any chemical engineering project. Naturally, the procedures for a small plant can be simplified and many short cuts can thus be made.

Between the inception of an idea to build a chemical plant and its realization in final concrete form, considerable engineering effort must be expended. To transform the ideas forming a chemical process into the materials which labor can handle and properly put together to produce an operating plant, requires the collaborative effort which is provided by organized engineering. Large engineering concerns through long years of experience have developed techniques, standards, and forms of organization which suit their requirements. Often these forms become fixed and inflexible so that these organizations operate under the handicap of excessive red tape. On the other hand, small concerns when first starting out often lack experience in the proper organization of work and therefore find it difficult to operate economically. However, when properly organized, the smaller engineering company can operate more efficiently and with a lower overhead than the larger less flexible concerns, and thereby gain a competitive advantage.

Scope of Project. The primary objective of a new engineering project is usually arrived at in discussions with the executives of the prospective client. This will determine the facilities to be installed or product to be manufactured as well as its quality, quantity, etc. At this stage the management or the client's engineers probably can estimate whether the addition of new facilities will be required to furnish the necessary power, water, steam, etc., for the projected plant. If no excess of these utilities is available or if their availability is limited, the determination of the magnitude of the new utilities requirements will have to await the completion of a detailed study of the process.

Cost Estimate. Assuming that the location of the plant has been settled either by executive decision or after a plant location study, the next point is to obtain a cost estimate. Preconstruction cost estimating of chemical process plants is a subject in itself, but one that

has been neglected by chemical engineers until a few years ago. Recently much information on chemical equipment costs (*5*, *8*) as well as over-all plant costs (*2*, *6*) has been published and has been summarized by Vilbrandt (*12*).

In contrast to general plant construction projects where the building is the largest cost item, in the chemical process plant the major cost is that of equipment. The capacity and size of this equipment have to be figured before a price estimate of the project can be made. Often the cost of piping in such a plant may be considerable and yet can be only roughly guessed at until the plant design has reached an advanced stage. It would be helpful to engineers, and estimators in the profession, if more piping cost data were published for various types of process plants.

Type of Contract. Due to the difficulties involved in estimating costs of chemical process plants, the question arises as to the kind of estimate to be made and the type of contract to be arrived at between the client and the engineering organization. R. C. Lewis (*3*) briefly discusses the merits of the cost-plus contract as against the lump-sum contract. The recent tendency, despite intensified competitive bidding on a lump-sum basis, seems to favor the cost-plus-fixed-fee contract which should logically be the basis for handling such highly variable equipment requirements as are called for in petroleum and chemical processes. This type of contract also takes into account the fluctuating prices of labor and equipment, so that an arrangement can be reached which is equitable both to the contractor and the client. Whereas the cost-plus-fixed-fee contract would not prevent the rush to sign contracts for plant construction at a time of rising prices, it would, however, tend to reduce the reluctance to enter into contracts in a falling price situation; since after the time taken to carry out preliminary engineering and preparation of specifi-

cations, the client would benefit by the lower prices prevailing at the time of equipment purchase.

It can now be assumed that a proposal submitted by the engineering firm has been accepted by the client and the contract signed for a "turnkey" plant to be furnished. This means that all the engineering, purchasing, and construction will be done by the contractor, and the plant when turned over to the client will be ready for operation. Sometimes, there are operating guarantees included in the contract and in such cases the engineering firm will have supervisory operating personnel at the plant and performance runs will be made before the client finally accepts the plant. On the other hand, contracts are made wherein it is stipulated that the contractor is responsible only up to the point of erection of the plant, at which time the client's engineers will take over the operation. This is usually done where the process is to be kept secret and outside engineers are not welcome.

Process Engineering. The engineering of a chemical engineering project originates in the process flow diagram which establishes the main operations to be performed on the starting materials in order to obtain the finished products and by-products. These operations are based usually on the chemistry and physics of the process and on the material-handling requirements. Many, if not all of these process steps may be known at the outset; on the other hand, some of these steps may have to be determined either by process calculations or by experimental procedures. Often, several alternative process flows, means of separation, and methods of heat exchange have to be figured and quick, rough, cost comparisons made before selecting the final process flow.

Basic information required for making process calculations generally consists of the following:

a. Analysis of raw materials
b. Specifications of products
c. Location of plant and characteristics of utilities, such as nature and quality of fuel, temperature of cooling water

When completed, the process calculations will provide:

1. Material Balance. This will include a detailed material balance for each individual piece of equipment as well as an over-all balance for the plant. For certain types of equipment such as condensers, where a change of state takes place, the material balance should be sufficiently detailed to give the quantities of vapor and liquid entering and leaving, since these will affect the design of this equipment. In the case of a distillation column, where the flowing quantities of liquid and vapor undergo large variations in the course of its height, several sectional heat and material

TABLE 1.—EQUIPMENT CLASSIFICATION SYSTEM

A—Foundations, piling and underground work, exclusive of piping.	L—Vessels, towers, fractionators, etc.
B—Buildings and fixtures	M—Vacuum equipment
C1—Piping, general	N—Insulation and fireproofing
C2—Piping, underground	O—Laboratory equipment
C3—Piping, instrument	P1—Pumps and drivers
D—Structural steel	P2—Compressors and drivers, expanders
E1—Electrical, lighting	Q—Sewers and drains
E2—Electrical power and switchgear	R—Instruments, scales, panel-boards
F—Furnaces, fired heaters, driers, stacks and flues	S—Storage vessels, tanks, drums, etc.
G—General equipment and any special equipment for a specific job—filters, evaporators, thickeners, cyclones, etc.	T—Painting
H—Heat exchangers, condensers, coolers	U—Unallocated materials for stock account
J—Converters, treating vessels, reactors, extractors, etc.	
K—Materials-handling equipment, conveyors, elevators, hoists, etc.	

Overhead Accounts

V—Engineering and drafting
W—Tools and equipment
X—Construction
Y—Insurance and taxes

balances have to be made in order to determine these internal flow quantities, which then furnish the basis for designing the trays and bubble-cap arrangement. Material balances should be expressed both in weight and volume quantities.

2. Heat Balance. Determination of the pressures and temperatures required in the various steps of the process provides the basis for figuring heat balances around each piece of equipment where any thermal change occurs. These heat balances determine the loads or duties for any heaters, coolers, etc. An over-all plant heat balance can be easily made to provide a check. Assuming the products leave the plant at the same temperature as the feed entering, then the sum of the external heating loads, as represented by the heat put into the plant by means of fuel and steam, should equal the sum of all the cooling loads, as represented by the heat removed from the plant by means of water or other cooling medium.

On the basis of all the just-mentioned quantities obtained by the material and heat balances, as well as by an ample allowance of liberally estimated pressure drops between various pieces of equipment, process specifications are developed for all the equipment in the plant. These furnish the normal quantities, temperatures, pressures, heat, duties, etc., for each of the various equipment items. In addition, the maximum (and in some cases minimum) quantities and duties should be specified also in order that the equipment have sufficient flexibility to perform as required.

For vessels, towers, and other special equipment, sketches are usually made showing locations of all nozzles, manholes, internals, etc., together with notes on the maximum operating pressure and temperature, corrosion allowance, and materials of construction.

Data accompanying heat-exchanger specifications include inlet and outlet temperatures, quantities of materials and their physical state, viscosities at specified temperatures, preferably in the range being handled by the equipment, and vaporization and condensation curves.

In furnishing data on pumps and compressors the normal and maximum flow quantities should be specified as well as the suction and discharge pressures. In addition to this, it is neces-

sary to state the specific gravity, viscosity and pumping temperature in the case of liquids; and the molecular weight and specific heat ratio C_p/C_v in the case of gases.

During the period of developing final process calculations, it is desirable to exchange knowledge of the process, and discuss preferences as to modes of operations, types of equipment, etc., with the engineers of the client company. This will save time and work in the later stages of engineering by reducing the number of revisions required.

If the process to be used is a new one, or if certain improvements on a previously used process are desired, it may be necessary to do some research and development work in the pilot plant before certain phases of the process can be determined. In such a case the proceedings can be expedited by transmitting to the project engineer the specifications for the equipment of that portion of the process which has been definitely established, with a short description of the nature of the unsolved problem and what probable equipment is involved. This will not only enable the project engineer to reserve some space on the plot plan and schedule the job, but also make some contributions to the solutions of the problem.

Project Engineering. The project engineering department of the organization carries the burden at this stage, its duties comprising the specifying and requisitioning of all equipment and materials, and the preparation of all drawings which are required for the erection of the plant. The person who guides this work to completion and who is the hub of the whole project, is the job or project engineer.

There is at times confusion as to the difference between a job and a project. Usual practice is to reserve the term project for a physically separate plant in a specified location. In turn this project may comprise several distinct but more or less interrelated units or sections which may be assigned distinct job numbers. In the case where the project consists of one or only a few
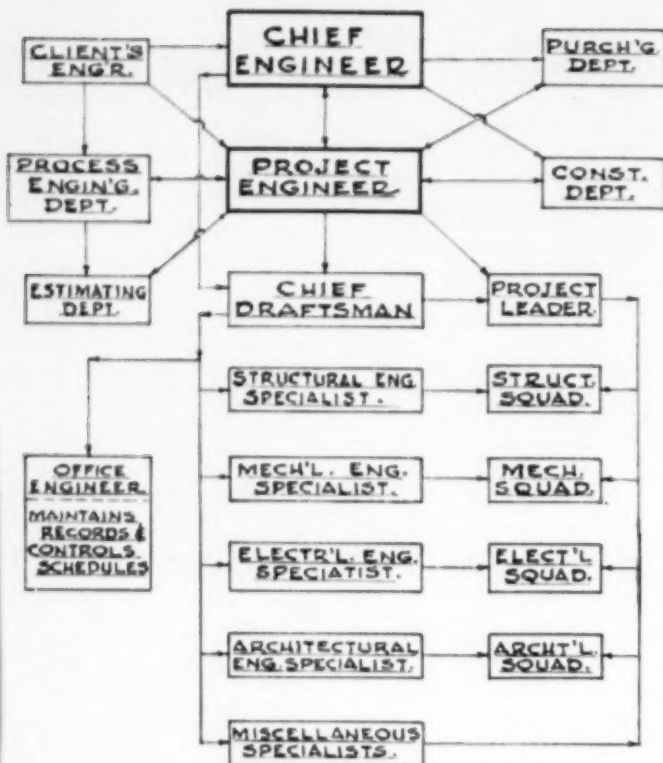
Fig. 1. Organizational Chart.

CHIEF ENGINEER — CLIENT'S ENGR. — PURCH'G. DEPT.

PROJECT ENGINEER — PROCESS ENGIN'G. DEPT. — CONST. DEPT.

ESTIMATING DEPT. — CHIEF DRAFTSMAN — PROJECT LEADER

STRUCTURAL ENG. SPECIALIST. — STRUCT. SQUAD.

OFFICE ENGINEER MAINTAINS RECORDS & CONTROLS SCHEDULES

MECH'L. ENG. SPECIALIST. — MECH. SQUAD.

ELECTR'L. ENG. SPECIATIST. — ELECT'L. SQUAD.

ARCHITECTURAL ENG. SPECIALIST. — ARCH'T'L. SQUAD.

MISCELLANEOUS SPECIALISTS.

separate units, the terms project and job may become synonymous, and similarly the terms project and job engineer. In the case where a project is fairly large, a job engineer may be assigned to each section or unit with a project engineer supervising and coordinating the overall engineering of the whole project. In the following discussion it will be assumed that the two terms are synonymous and that the job at hand involves the construction of a moderately sized plant.

Even though the project engineer is the hub of the undertaking he cannot succeed unless he has an organization which is geared to handle the various components of the project. Figure 1 shows the interrelationship between project engineer and the rest of the engineering organization. This chart places the project engineer in the key position and shows whence his directives emanate and in what direction his responsibilities are channeled. Process information and equipment specifications are transmitted from the process department. The client's engineers have certain requirements as to specifications, standards, interchangeability of equip-

ment, safety, etc. The project engineer is apprised of the estimated cost of the job being handled and will have occasions to call on the estimating department to make cost comparisons of several alternative schemes devised to accomplish certain engineering requirements. He should collaborate with the purchasing department in the selection of bidders, and by obtaining copies of all purchase orders he can make sure that all the equipment for the job is ordered. Over-all guidance and directives as to general policy, costs, time schedules, etc., come from the chief engineer.

All information coming to the project engineer has to be channeled into two main directions: (1) In the form of engineering data, sketches, flow sheets, etc., which are furnished to the drafting room, whence they eventually emerge in the form of plot plans, engineering flow sheets, detailed equipment layouts and piping arrangements together with Bills of Material and (2) In the form of purchase orders covering all equipment and materials required for the construction of the plant from raw materials to laboratory instruments; from elevators

to hardware for doors and the proverbial plant whistle.

The organization of engineering drafting rooms varies with different companies. The writer believes that the most satisfactory arrangement is the one outlined in Figure 1. This calls for the chief draftsman to create under him various departments or groups of specialized personnel, such as structural, mechanical, etc. Each group is led by a competent engineer who is a specialist in that field and who normally directs the work of the men in his group and sets up standards and procedures.

When a project is to be started the chief draftsman selects one of the more experienced men from any one of these groups and sets him up as the project or group leader in the drafting room. The chief draftsman also assigns certain personnel from each of these specialized groups to work on the particular project under the group leader. These draftsmen, supervised by the group leader, carry on all the detailed design and drafting. The whole group works under the jurisdiction and guidance of the project engineer. However, in technical matters the draftsmen look to the chief engineer of their special group for advice and consultation and all their drawings are signed by the chief engineer of that particular group. Thus electrical drawings are signed by the chief electrical engineer, steel and foundation drawings by the chief structural engineer, piping drawings by the chief mechanical engineer, etc.

The group leader acts as liaison between the job engineer and the drafting room. The work required is explained to him and he in turn directs the detailed execution of this work by the draftsmen. He also carries out the important function of coordinating the various phases of the work of the different special groups. For example he provides the men who are designing the structural steel with drawings showing the arrangement of equipment including location of foundation bolts, etc. Conversely, he gives structural steel drawings to the men who are working on piping, so as to avoid such commonly encountered errors as showing piping going through structural beams, or underground lines going through foundations.

It is often advantageous, whenever possible, to assign the project engineer to the particular project in advance of completion of final process information. This enables him to go ahead and obtain information regarding the plant site, its elevation contours, characteristics and availability of all utilities, and soil-bearing pressure. If the plant is an extension of, or is to be located adjacent to, another plant, the surplus of

the utilities available should be determined since these may be adequate for the new addition. Otherwise, additional wells may have to be dug, boilers installed and transformers added.

The project engineer's first work concerns the establishment of the procedural method to be followed and the notification of all other departments involved. Most engineering and construction organizations have established accounting systems which cover all phases of a construction job. In the construction of a chemical or petroleum project the equipment constitutes by far the major portion of the job and various construction classifications are of minor interest. Lewis (3) has discussed this subject insofar as it affects the accounting and construction phases. Concern in the present discussion is with a classification of equipment as it affects the engineering phases of a project. Presented in Table 1 is a typical refinery code classification system and from the inception of the job the code letters, together with an appropriate number, are used to designate various items of equipment in the plant. These numbers are carried throughout all the phases of the job such as requisitions, purchase orders, engineering drawings and finally are put on tags or name plates to identify the equipment and to designate its location in the field upon delivery.

When used for a small plant or one operating unit, the equipment can be numbered with the group letter followed by consecutive numbers, e.g.,

Distillation towers .... L-1, L-2, etc.
Pumps .... P1-1, P1-2, etc.

In this type of classification the drivers of units take the number of the equipment they are driving, followed by a symbol to designate the type of driver, e.g., a motor for pump P1-6 would be P1-6M whereas a turbine for this pump would be numbered P1-6T. When a large plant is being constructed, it is usually divided into numbered sections. The section number then precedes the equipment number to identify its location, e.g.,

	Section 20	Section 30
Pumps	20 P1-1, 2, etc.	30 P1-1, 2, etc.
Exchangers	20 H-1, 2, etc.	30 H-1, 2, etc.

When the project engineer receives the flow sheets, equipment specifications and sketches from the process department, he can proceed then with his work. The first thing in order of importance is to send out requests to bid on the major equipment and those other items which take longest to manufacture and deliver. This will include special vessels, reactors, dryers, filters, evaporators, pumps, turbines, motors, etc. In connection with equipment which requires special design such as converters, reactors, fermenters, etc., it will be necessary to concentrate on their design in the beginning in order to develop sufficiently detailed drawings to enable fabricators to submit quotations.

Initiation of requests to bid can be handled in several ways. A typical procedure is for the project engineer to prepare sketches, drawings, specifications, and an itemized schedule covering each specific type of equipment. He then transmits this information to the purchasing department together with a purchase requisition and a list of possible suppliers. The purchasing department sends out the requests to bid and transmits to the project engineer a copy of each bid when it comes in.

In all requests to bid on equipment it is important to state the information which is required with the quotation. The bidder should be requested to submit in addition to price, delivery, and equipment details, such information as weight and approximate size or floor space required. The information on floor space will enable the project engineer to proceed with equipment layout and plot-plan studies considerably in advance of the time when detailed equipment drawings become available, whereas the approximate equipment weight can be used for foundation design. This will usefully fill in the wide gap in time between the final selection of equipment and the receipt of certified drawings from the manufacturers.

Accompanying each request to bid there should be complete information on the quantities to be handled, performance expected of all items of equipment as well as the desired quality of materials of construction. These requirements are embodied in a set of specifications made up for each group of materials or each type or class of equipment, required in the plant. For example, piling, pressure vessels, atmospheric tanks, centrifugal pumps, reciprocating pumps, heat exchangers, each type of control instrument, piping, insulation, etc.

In specifying materials there is generally required some guarantee, as to quality or workmanship, while on equipment items there are usually requirements as to performance, inspection, testing, certified drawings, marking and shipping. Often these latter requirements are incorporated in the purchase order to the successful bidder, hence it is advisable to include them in the original specifications upon which the supplier is requested to quote. In the case where the equipment is for a foreign job, this should be so stated, since the supplier is generally expected to furnish the equipment packed for export and suitably protected against the weather, for which there is an additional charge.

In specifying the requirements for pumps and compressors, it is usual to call for an excess capacity of 10-25% over the normal requirement and especially for an ample allowance of differential pressure. This latter item is important since at the time of specifying the operating conditions for the pump or compressor, a layout or piping arrangement will not yet have been made, so that a detailed pressure-drop calculation cannot be figured. Such a detailed check will have to await a later date and it is often found that the process engineers have erred on the side of a low pressure-drop estimate and that the calculated pressure drop is greater than the purchased unit can put up. In such a case a major change in the piece of equipment is required with the resulting increase in price and loss of time in delivery. As regards other general specifications it is advisable to include as many specific requirements and details as are known to be required for the particular service even if this eliminates some suppliers from the field. In many instances the client's engineers will insist on certain requirements being met and specific features included.

While inquiries are out for the major equipment, piping specifications have to be prepared defining the quality and pressure and temperature limitations for the pipe, valves, fittings, etc., which are to be used for the various services. These specifications are used then by the draftsmen on all the piping drawings made for the job. Insulation, electrical and other specifications also are to be prepared at this time.

Equipment layout studies are started as soon as a fair idea of the number of equipment items and their approximate size is obtained.

The basic considerations which affect the arrangement of equipment are:

a. Most economical layout
b. Ease and safety of operations
c. Suitability for servicing and maintenance
d. Aesthetic and architectural appearance

All these factors (a-d) should be given due consideration and it can be stated that c and d are as important as the first ones. For it has been proved that a clean and neat appearance of layout and equipment has an influence on the spirit of the workers and on their accident potentialities. The attractive appearance of a plant can also be used

for advertising and publicity purposes.

A good method for arriving at a satisfactory plot plan is to turn the problem over to several men to work on it independently. In this way different plans will result and the best features of each can be incorporated in the final plan.

When the approximate equipment weights and dimensions have been obtained, the design of the foundations can be gone ahead with, subject to final check when certified equipment prints are available. At that time the bolt holes for the equipment base plates are also definitely located.

Most of the work already mentioned has been of a preparatory nature but now the purchases of the major equipment items begin.

When equipment bids are received a bid comparison is made by the project engineer, or his assistant, in order to compare the engineering features of the various equipment. Often the bids offer different types of equipment for the same service, in which case further discussions as to performance are entered into with the vendor's representatives, and an evaluation of the comparative merits of the equipment is made. This emphasizes the importance of having the bid comparison made by the project engineer who then sends it in to the purchasing department with his recommended supplier. Although the privilege of final decision on purchases usually rests with the purchasing department, the project engineer should be consulted on the final selection, since it is his responsibility to select proper and satisfactory equipment.

Flow Diagrams. Among the first drawings to be prepared is the engineering flow diagram which together with the plot plan forms the basic design plan, by which the whole plant is engineered. This flow diagram shows the plant equipment and the interconnecting lines, valves, instruments, etc. In some cases the line size and specification are indicated on the lines of this diagram, in other cases there is a line schedule tabulation on one side of the drawing or a separate line schedule accompanying each drawing. This schedule usually gives the line number or designation, service, size, pressure and temperature rating and piping specification. In order to avoid a crowding of lines when the flow diagram is complicated, only the process lines are shown and separate utility flow diagrams are made showing the water, steam, gas, etc., lines going to each equipment item. Separate drawings are also made showing all the electrical lines connecting up with the plant equipment and motors.

In the course of engineering the chemical plant special problems arise. Flow sheets and design calculations

have to be made for individual systems such as refrigeration, pressure relieving, oil separators, waste disposal, and special instrumentation. The steam and water distribution to the various equipments is studied and the system so arranged as to give the most economical operation. Time cycles of various operations also have to be studied and coordinated.

Piping Drawings. At each equipment item detailed piping drawings are made showing plan views at several levels, elevations, sections, etc., as the need in each case requires. Similarly detailed drawings of structural steel work have to be made for building frames, equipment supports, ladders, platforms, etc. Accompanying each of these drawings is a Bill of Material which lists all the material required to construct or fabricate whatever is shown on the drawing. These Bills of Material then furnish the basis upon which material for the plant is ordered.

Some engineering organizations base all purchase orders on Bills of Material; however, it is much simpler to order all the larger mechanical equipment items including pumps, compressors, heat exchangers and instruments on the basis of equipment schedules and specifications. This will leave piping, structural materials and miscellaneous items, obtained from a detailed take-off from drawings, to be purchased on the basis of Bills of Materials. In this connection, it is important for the job engineer to keep an up-to-date master set of BM's and mark opposite the various items which he orders, the purchase order number covering those items. Frequently, certain raw materials have to be ordered in advance in time for fabrication, e.g., structural steel, piping, insulation. In such cases an estimate is made on the basis of a rough material take-off and ordered on a Stock Bill of Material. Then as each drawing is prepared its requirements are subtracted from the Stock Bill of Material and if necessary additional material ordered.

One of the prime functions of the project engineer, and ranking second in importance only to the purchase of equipment, is the guidance of the project through the drafting room. This requires the supervision and coordination of the various groups in the drafting room working on vessel design, foundations, structural steel, piping, etc. As previously described this can be carried out through a group leader in the drafting room.

After sizing the pipe lines, a detailed pressure check of the whole plant should be made, based on the actual or tentative piping layout. Where the pressure drop in a system is found to be excessive, it will be necessary to enlarge some line

sizes or raise the discharge pressure of some pumps or compressors. Where the situation warrants it, and time permits, the most economical pipe-size selections for the whole plant can be figured in accordance with the formula developed by Sarchet & Colburn *(8).*

All drawings for the project are checked by the project engineer, or his assistants, and are distributed by him to the various parties concerned. Some drawings are transmitted to the purchasing department to be used as the basis for purchasing various materials. When drawings are finalized and all anticipated revisions have been made, copies are sent to the construction department or to the construction superintendent in the field. Among the first drawings required in the field are those for foundations and underground piping, after which come equipment assembly drawings and lastly piping drawings.

Conclusion of Project

In preparing for the initial operation of the plant detailed operating instructions have to be prepared which will describe the general procedure to be used, hazards involved, precautions to be taken, and the anticipated operating conditions. The shutting-down procedure is also described. Forms for the operating log sheets are prepared as well as flagged flow diagrams *(6)* whereon to report conditions during operation. In addition to furnishing an operating record of the plant, these form the basis for checking the actual operation versus the designed conditions and provide information for making improved designs of future plants.

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COLUMBUS
MEETING
PROGRAM

ARTICLE BY J. A. GRANT

COLUMBUS, in the center of the Buckeye state, will be host to A.I.Ch.E. members for the second time when they assemble Dec. 3-6 for their Forty-third Annual Meeting. Attendance at the Columbus meeting in 1935 was 235. This year, it is expected to be more than 1500. A well-known convention city, Columbus is well suited to receive and entertain the engineers and their ladies.

Attractions of the December meeting will be the second Institute Lecture, a list of general papers, four symposia, the Awards Dinner on Tuesday evening, Dec. 5, and a wide choice of plant trips in the Columbus area. Carefully prepared programs for the ladies and special entertainment features are part of the plan to make the meeting an enjoyable one.

Both the Neil House and the Deshler-Wallick Hotel will be used as headquarters. Registration headquarters will be at the Neil House. Members are urged to preregister for their greater convenience.

Institute Lecture

The Institute Lecture will be given by Olaf A. Hougen and will precede the business meeting on Monday morning, Dec. 4. Dr. Hougen's subject will be "The Status of Applied Kinetics." This rapidly advancing field of chemical engineering is of prime importance in modern practice. For this reason, the

lecture will appeal to chemical engineers in all branches of the profession.

Conception of the Institute Lecture is credited to F. J. Curtis, Past President of A.I.Ch.E. His idea was that a critical summarization of knowledge by an outstanding authority in some particular field would be highly beneficial to Institute members. The first such lecture was given at the December, 1949, Pittsburgh meeting by Prof. W. H. McAdams on the subject of heat transfer.

O. A. Hougen to Give Second Institute Lecture

Awards at Banquet

Chief interest at the banquet Tuesday evening, Dec. 5, will center about the introduction of newly elected officers and the presentation of awards.

Professional Progress Award. This award is sponsored by the Celanese Corporation of America. It consists of $1000 and a certificate given in recognition of outstanding progress in the field of chemical engineering for the betterment of human relations and circumstances. The award was first given in 1948 at New York to Dr. Allan P. Colburn, University of Delaware. Last year's recipient was Dr. Mott Souders, Shell Development Co.

William H. Walker Award. Administered by the Institute Awards Committee, the award is presented to a member of the A.I.Ch.E. who has made an outstanding contribution to the literature of chemical engineering. The purpose of the award is to stimulate interest in improving quality, clarity of expression, and practical utility of contributions to this literature. The recipient must be the author or coauthor of an outstanding paper published by the Institute during the preceding three years. In addition to giving the first Institute Lecture, Prof. W. H. McAdams, Massachusetts Institute of Technology, received the William H. Walker Award at the 1949 annual meeting.

TECHNICAL PROGRAM

Monday, Dec. 4, 1950

Morning Session beginning at 9:00 A.M.

W. L. McCabe, presiding

Second Institute Lecture.—*O. A. Hougen, "The Status of Applied Kinetics"*

Annual Business Meeting A.I.Ch.E.

Afternoon Sessions beginning at 2:00 P.M.

Session No. 2
(simultaneously with Session No. 3)

R. L. Savage, presiding

General Technical Symposium

Fundamental Factors Affecting Mass Transfer Rates on Bubble Plates.—*J. A. Gerster, W. E. Bonnet and I. Hess*

Packing Efficiencies in a 1-foot Diameter Column.—*J. F. Ryan and M. R. Cannon*

Spiral Weave Metallic Cloth as a Packing Material for a Stripping Column.—*L. K. Arnold and R. D. Ingebo*

Heat Transfer From Parallel Plates to Air Flowing at Low Velocity.—*E. R. Irish and G. O. Lof*

Constant Rate Filtration.—*O. D. Hughes, R. W. Ver Hoeve and C. D. Luke*

Session No. 3—Ultrasonics Symposium

Dudley Thompson, presiding

Basic Principles of the Application of Sonic and Ultrasonic Energy.—*E. A. Hiedemann*

On the Mechanisms of Biological Effects Produced by Ultrasound.—*T. F. Hueter*

Kilowatts of Ultrasonic Power for Industry.—*J. W. Butterworth*

Physical and Economic Limitations in the Application of Sonic and Ultrasonic Energy to Industrial Processes.—*R. W. Samsel*

Tuesday, Dec. 5, 1950

Morning Sessions beginning at 9:20 A.M.

Session No. 4
(simultaneously with Session No. 5)

Chemical Engineering in the Glass Industry Symposium

F. C. Flint, presiding

Refractory Problems in the Melting of Glass.—*C. G. Harman and J. D. Sullivan*

Chemical Engineering Aspects of Flat Glass, Glass Block, and Foamglas.—*A. H. Baker and R. A. Miller*

Glass—A Material for the Chemical Industry.—*E. B. Shand*

The Process of Fracturing of Glass.—*F. W. Preston*

Session No. 5—Phase Equilibria Symposium

W. C. Edmister, presiding

Isobaric Liquid—Vapor Equilibrium Calculations.—*M. Nord*

Pressure-Volume-Temperature-Composition Relationships for Binary Hydrocarbon Systems. Part I. Methane-Isopentane.—*B. F. Dodge, E. H. Amick and W. B. Johnson;* **Part II. Toluene-n-Hexane.**—*B. F. Dodge and L. M. Watson*

Vaporization Equilibria of Methane at High Pressure.—*J. H. Arnold*

Afternoon Sessions beginning at 1:50 P.M.

Session No. 6—General Technical Symposium

(simultaneously with Session No. 7)

M. C. Rogers, presiding

Visual Perception and Learning.—*H. L. Sherman*

The Design of a Continuous Cold Rubber Process.—*M. W. Larson*

Alumina Activated With Anhydrous Hydrogen Fluoride as a Dealkylation Catalyst for Aromatic Hydrocarbons.—*L. Berg, E. O. Kindschy, W. S. Reveal and H. A. Sauer*

Liquid-Phase Hydrogenation of Coal at Low Pressure.—*E. L. Clark, R. W. Hiteshue, H. J. Kandiner and H. H. Storch*

Esterification—Continuous Noncatalytic Production of the Lower Acetates.—*L. Berg and J. A. Runberg*

Session No. 7—Phase Equilibria Symposium

W. C. Edmister, presiding

Liquid-Vapor Equilibrium in Mixtures of Light Hydrocarbons and Absorber Oils.—*E. Solomon*

Vapor-Pressure-Temperature Correlations for Hydrocarbon Mixtures in Batch Differential Vacuum Distillation.—*G. G. Lamb and I. J. Sitar*

Liquid-Vapor Equilibrium Relations in Binary Systems.—The Ethane-Benzene System.—*W. B. Kay and T. D. Nevens*

Vapor-Liquid Equilibria for the Binary System Hydrazine and Water.—*R. Q. Wilson, H. P. Munger and J. W. Clegg*

Wednesday, Dec. 6, 1950

Morning Sessions beginning at 9:20 A.M.

Session No. 8
(simultaneously with Session No. 9)

Symposium on Processing of Viscous Materials.—*W. W. Kraft, presiding*

Practical Mixing Techniques for Viscous Materials.—*H. L. Bullock*

Pressure Drop of Fluid Polystyrene in Conduits.—*R. M. Wiley and J. E. Pierce*

Heat Transfer in the Processing of Viscous Materials.—*F. E. Reese and E. Perry*

Flow Properties of Thermoplastic Polymers.—*E. T. Severs and R. L. Pigford*

Session No. 9—Symposium on Air Pollution Control

R. D. Hoak, presiding

Techniques for the Study of Air Pollution at Low Altitudes.—*H. P. Munger*

Dispersion from Short Stacks.—*C. A. Gosline*

Electrostatic and Sonic Precipitation.—*H. W. St. Clair*

Performance of Industrial Aerosol Filters.—*L. Silverman*

The Control of Air Pollution in the Chemical Industry.—*M. Sittenfield*

Afternoon Sessions beginning at 2:30 P.M.

Session No. 10—General Technical Symposium

(simultaneously with Session No. 11)

B. A. Smith, presiding

Drying of Drops.—*W. E. Ranz and W. R. Marshall, Jr.*

Atomization of Water With Spinning Disks.—*C. R. Adler and W. R. Marshall, Jr.*

Atomization With Centrifugal Pressure Nozzles.—*R. W. Tate and W. R. Marshall, Jr.*

An Electronic-Drop-Size Distribution Analyzer.—*C. R. Adler, A. M. Mark, W. R. Marshall, Jr., and R. W. Tate*

Centrifugal-Disk Atomization.—*S. J. Friedman and S. A. Gluckert and W. R. Marshall, Jr.*

Session No. 11—Symposium on Air Pollution

R. D. Hoak, presiding

Disposal of Radioactive Gases.—*W. R. Eister*

Principles for the Study of Air Pollution by Particulate Matter.—*W. C. L. Hemeon*

Session No. 12 (following Session No. 11)

General Technical Symposium.—*E. M. Schoenborn, presiding*

Fluidization of Solid Particles.—*R. D. Toomey and H. F. Johnstone*

Continuous-Flow Stirred Tank Reactor Systems—Agitation Requirements.—*R. W. MacDonald and E. L. Piret*

Correlation of Operating Variables In Dewatering by Centrifugation.—*E. P. Barthus and H. P. Simon*

Junior Award. Patterned after the William H. Walker Award, but open only to Junior members, the Junior Award is similarly administered. Recipients are selected from among authors or coauthors of papers published by the Institute during the preceding three years. The Award, first given in 1945, was presented last year to Edward G. Scheibel, of Hoffmann-LaRoche, Inc.

A. McLaren White Award. Prizes are given to winners in the Annual Student Contest for the best solutions of a problem in chemical engineering. This honor is the Institute's oldest, having been started in 1932. First, second, and third prizes, and occasionally more than one honorable mention, are awarded.

Technical Program

The program, which is listed in this issue, promises to be both full and interesting. In addition to a varied group of general papers, four symposia of four to eight papers each have been planned.

Ultrasonics. This symposium is scheduled for Monday afternoon, Dec. 4, with Dudley Thompson, Virginia Polytechnic Institute, as chairman. It is a continuation of previous symposia held at the Houston and Swampscott Regional meetings. In view of the interest created in this new chemical engineering tool, this symposium will continue to attract a large number of engineers.

Chemical Engineering in the Glass Industry. On Tuesday morning, Dec. 5, four papers will be presented which deal with various aspects of the glass industry. The increased use of glass in var-

Aerial View of Ohio State University Campus.

ious forms in plant construction, process equipment, and packaging will be emphasized in this timely symposium presided over by F. C. Flint, Hazel-Atlas Glass Co., Washington, Pa.

Phase Equilibria. Wayne C. Edmister, Carnegie Institute of Technology, continues a symposium initiated at Houston. Originally scheduled for only the Houston and Minneapolis Regional meetings, the interest and response were such as to justify the Tuesday morning and afternoon session at the Columbus meeting. Eight papers will deal with such topics as phase relations in hydro-

carbon and hydrazine-water systems, as well as correlation methods.

Air-Pollution Control. The chemical process industry, always among the leaders in applying the most advanced knowledge to the solution of its problems, has, for a long time, been aware of its responsibility to the public in matters concerning pollution of the atmosphere and waterways. This symposium will describe some of the efforts of chemical engineers to avoid and combat air pollution. Six papers, comprising measurement and preventative process

Seated (left to right): F. D. Peterseim, Battelle Institute, Plant Trips; R. C. Johnston, Ohio State University, Plant Trips, and E. J. Bradbury, Battelle Institute, Registration. Standing: K. Jacobs, Ironside Co., Printing.

Seated: Mrs. W. T. Maidens, Ladies' Committee, and W. T. Maidens, American Zinc Oxide Co., Plant Trips. Standing (left to right): F. C. Croxton, Battelle Institute, Co-Chairman, and J. H. Koffolt, Ohio State University, Co-Chairman.

MANAGEMENT THEME DOMINATES MINNEAPOLIS MEETING

THE Twin City Section of the A.I.Ch.E. opened the doors of hospitality, in the land of the sky-blue water, for five-hundred chemical engineers last month. The Minneapolis-St. Paul local section, which is less than a year old, staged smoothly and efficiently the largest technical program ever given at a regional meeting of the A.I.Ch.E. The double sessions, which are getting to be standard at Institute meetings owing to its growth, were well attended, as were the plant trips in an industrial area which is the largest flour-milling center in the world and which processes most of the country's flaxseed into linseed oil and oil cake. Under the leadership of the General Chairman Robert J. Foster, the local group achieved a cohesiveness in operation which helped make this meeting as efficient and memorable as those run by older and more experienced local groups.

One of the most interesting developments during the meeting was the management test given the first morning, as part of the symposium organized by Loren P. Scoville of Jefferson Chemical Co., on What Should You Know about Management. A group of 182 chemical engineers took the test of the American Management Association entitled, "Self-Analysis Quiz for Supervisors and Executives." The chemical engineers flunked the quiz, which was devised by Rexford Hersey, associate professor of industry, Wharton School of Finance and Commerce, University of Pennsylvania, was divided, Part I having 58 questions and Part II having 29 questions. According to the management expert, if more than three questions were missed in Part I, it indicated that knowledge of good supervisory practices was on the weak side and needed

careful scrutiny. As a group the chemical engineers missed six questions, both as an average and as a median, with the mode (the number which turned up most frequently) as 4. That some chemical engineers were good supervisors, according to the test, was indicated by the range of missed questions, which began at one wrong, and that some chemical engineers were badly in need of supervisory training was indicated by the upper limit of the range —15 missed.

R. J. Foster, General Mills, Inc., Chairman, Committee on Arrangements.

For the second part which was intended for those on higher supervisory or executive levels "more than four errors," said the test preface, "is indicative of weakness in knowledge of managerial principles and in analytical ability."

Again as a group the chemical engineers failed. This time worse than before. The number wrong averaged 10.5, the median was 10, the mode was 9, with the range being zero to 21.

Indications that chemical engineers had flunked were given before the meeting disbanded, and most of the difficulty was attributed to the speed at which the test had been given and the informal conditions which fostered a tendency to misunderstanding the questions. While there was no demand for a recount or for a re-performance, it was strongly intimated that this possibly indicated something wrong with American management, that it did not have the chemical engineer's unique approach to the problems represented by the questions.

Members of the American Institute of Chemical Engineers and their guests were welcomed to Minneapolis

by Lloyd A. Hatch, vice-president of the Minnesota Mining & Manufacturing Co. In his address Mr. Hatch remarked that he was favorably impressed as the meeting program held two symposia which departed from the strictly technical aspects of chemical engineering, namely the management and economic symposia. He stressed the idea that the chemical engineer's responsibility to society is more important than his technical contribution to industry. He is important, he said, to the theoretical sciences of physics and chemistry for the translation of their ideas into production; to financial interests for developing the methods of gainfully employing capital; to labor for the means of creating new jobs; and to the consuming public in order to raise its standard of living. Mr. Hatch voiced the hope that papers on management and the chemical engineers' relation to society would become a part of every A.I.Ch.E. meeting program. "Too many highly proficient technical men," he said, "are economically speaking, quite illiterate. The chemical engineer must be better trained to think through his problems and his relations." This responsibility, he explained, cannot be left entirely up to the universities. Older men in industry must devote more of their time to the men that will one day succeed them.

Technical Sessions

The technical program Monday morning began with two symposia, one on phase equilibria and the other on problems of management. Both continued through morning and afternoon sessions.

The two sessions on phase equilibria were conducted by W. C. Edmister, Carnegie Institute of Technology, who initiated a series of symposia on this

S. L. Tyler, Secretary of A.I.Ch.E., and Edgar L. Piret, Univ. of Minn., Technical Program Chairman.

Lloyd A. Hatch, Vice-President, Minnesota Mining & Mfg. Co., chatting with W. L. McCabe, President, A.I.Ch.E.

Speakers at the chemical plant construction symposium. Homer Kieweg, Commercial Solvents Corp.; H. S. Kemp, Du Pont Co.; W. H. Williams, Dow Chemical Co., and J. R. Minevitch, E. B. Badger & Sons Co., symposium leader.

Rear: H. B. Irvin, Phillips Petroleum Co.; R. A. Buckley, Univ. of Wisconsin; A. Kivinik, Univ. of Pennsylvania; T. Baron, Univ. of Illinois, and C. E. Sanborn, Shell Development Co. Front: R. W. Baker, Univ. of Wisconsin; Charles Potter, Columbia University; H. J. Kandiner, U. S. Bureau of Mines.

D. L. Katz, Univ. of Michigan, and W. E. Lobo, M. W. Kellogg Co.

subject at the Pittsburgh Annual Meeting in 1949.

The symposium "What Should You Know About Management," presided over by L. P. Scoville, Jefferson Chemical Co., was extremely popular. In his opening remarks Mr. Scoville pointed out that chemical engineers have an excellent background and training for proceeding to high managerial positions. He cited, to prove his point, the names of several well-known chemical engineers who have become presidents of large companies in the chemical industry.

Chaplin Tyler, Du Pont Co., asked the question in the title of his presentation, "Are You of Executive Caliber?" He submitted a yardstick, which was developed from 30 years' observation of a number of executives at work in various levels of management, by

which to measure attributes of leadership.

Stanley P. Farwell, Business Research Corp., held an attentive audience with his paper, "How is Your Salary Determined?" He spoke in favor of all companies having a definite salary policy including one for high level positions. The crux of any salary policy, he continued, lies in a proper job evaluation program.

"Applied Reaction Kinetics" was the title given to a third symposium presided over by R. H. Wilhelm, Princeton University. Nine papers covering the subject were presented. J. R. Caddell and D. M. Hurt, Du Pont Co., in their paper, "Principles of Reactor Design," extended the number-of-reaction-unit concept to cover other than first-order reactions where its use originated.

H. B. Ogburn and R. H. Wilhelm presented results of an electric analogue analysis of conditions existing in fixed-bed catalytic reactors. Using as an experimental system the catalytic hydrogenation of ethylene, a comparison was made between calculated and experimental results on temperature gradients and conversion levels.

"Quantitative Economics in the Estimation of Risk Factors in Capital Ventures" was the title of a fourth symposium organized by Mott Souders, Jr., Shell Development Co. The introductory paper was given by Mott Souders, Jr., "Population, the Base of the Econ-

The Public Relations Committee at work: C. W. Bentz, L. D. McClusky, Minnesota Mining & Mfg. Co., and W. M. Podas, Chairman, Economics Lab., Inc.

A. G. Smith, C. C. Japs and R. W. Schilling of Minnesota Mining & Mfg. Co., members of the Registration Committee.

L. P. Scoville, Jefferson Chemical Co., who presided over the Management Symposium; R. H. Wilhelm, Princeton University leader of Reaction Kinetic Symposium; Chaplin Tyler, Du Pont Co.; W. H. Goss, Pillsbury Mills, Inc.; A. W. deVout, Swift & Co. (top to bottom).

NEW CONTACT PROCESS FOR MAKING SULFURIC ACID
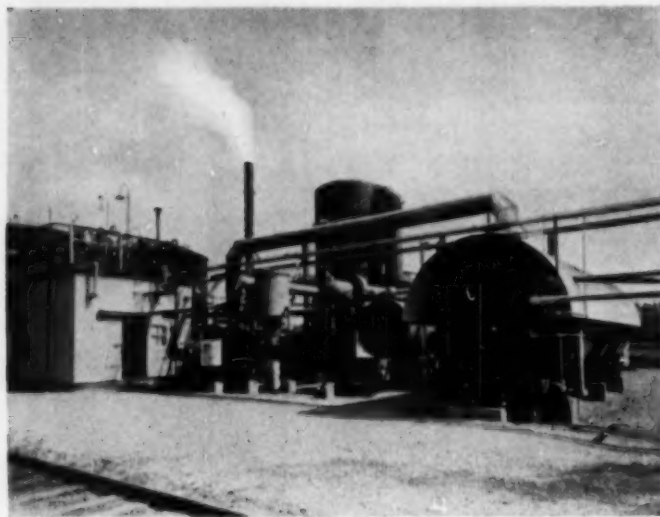
Chemical Construction Corp., New York, has developed a new design in contact-sulfuric acid manufacture which eliminates seven major items of equipment, and a commercial-size plant, shown above, embodying the new design has been in operation since early June of this year at American Cyanamid's works at Hamilton, Ohio.

The new design is simpler than the conventional contact process, and represents an estimated saving of as much as 20 per cent of the present capital cost of a medium sulfuric acid plant.

The new process followed the development of a quench converter, bubble absorbers, using evaporative cooling, and a low cost Pease-Anthony venturi sulfuric acid mist eliminator.

Traditional components of conventional contact installations which were eliminated were a drying tower, gas filter, heat exchanger between primary and secondary converter, sulfur trioxide cooler, acid coolers, acid transfer pumps and piping, and the dilution system, consisting of dilution tank, pumps and cooler sections.

Elimination of the drying tower made it necessary to omit all heat-exchange surfaces as potential corrosion hazards and the quench-type converter was developed to solve the problem of interstage cooling.

Catalytic oxidation of sulfur dioxide is carried out in four successive stages. Temperature control is effected by admitting cold, atmospheric air between the converter stages.

With burner gas containing 12 per cent sulfur dioxide by volume and using a catalyst loading equivalent to that of conventional contact converters, conversion of SO_2 to SO_3 in excess of 99% is claimed. The entire heat load provided by the sensible heat of the gases leaving the converter as well as the heat of acid formation is removed by evaporation of water in a staged absorption system.

This design will produce 95% acid. Acid transfer is by gravity.

The venturi scrubber is essentially a venturi tube. Mist-laden gases leaving the low-stage absorber are scrubbed in the throat at a high velocity by means of a recirculated stream of dilute sulfuric acid solution. The high degree of turbulence prevailing in the venturi throat achieves intimate contact between the gas and scrubbing medium. Entrained liquid leaving the venturi is removed from the gas stream in a cyclone mist separator. Exit gases contain only about one tenth of the acid mist which leaves a conventional contact plant absorption tower.

PITTSBURGH DIFFRACTION CONFERENCE

The Eighth Annual Pittsburgh Conference on X-Ray and Electron Diffraction will be held at the Mellon Institute, Pittsburgh, Pa., Nov. 2-3, 1950. Two distinguished French scientists will address the conference, which will sponsor an exhibit of diffraction cameras and other accessories and equipment. The conference dinner will be held Nov. 2 at the Faculty Club of the University of Pittsburgh.

The tentative schedule includes a symposium on Small Angle Scattering, on Silicate Chemistry, Instrumentation, and one on Metals.

Write for information to C. W. Cline, Aluminum Research Laboratories, P.O. Box 772, New Kensington, Pa.

C-BLACK PLANT FOR WITCO-CONTINENTAL

Organization of a new company, Continental Oil Black Co., was announced last month by R. I. Wishnick, president of Continental Carbon Co., and L. F. McCullom, president of Continental Oil Co., joint owners of the new enterprise. A $1,500,000 plant will be erected at Lake Charles, La., designed to manufacture 25 million pounds annually of high abrasion furnace black from oil. The announcement followed action by the Louisiana Board of Commerce and Industry in approving a ten-year tax exemption for the new plant.

Contracts for the Lake Charles carbon black plant have been signed and construction will begin immediately. The plant will be located just east and adjacent to Continental Oil's refinery and is scheduled for completion early in 1951.

Raw material for the new plant will be piped direct from Continental Oil's refinery.

The recent government directive designed to conserve the use of natural rubber, plus the rise in the use of "cold rubber" is expected to stimulate substantially the demand for high abrasion furnace black. A portion of the output of the carbon black will be funnelled into the expanded synthetic rubber production along the Gulf Coast.

The Witco Chemical Co. of New York will be distributors of the plant's production.

NEW FURFURAL PRODUCTION UNIT

A new plant to make furfural is under construction in Omaha, Nebraska, for the Quaker Oats Co. This plant will be similar to the Quaker plant located at Memphis, Tenn., which was purchased for approximately $1,500,000 in 1946. However, the plant at Omaha will contain no power plant and the Omaha Public Power District will furnish processed steam and power. The Omaha plant brings the total number of Quaker plants to 15 major units located as far East as Depew, N. Y., and on the West Coast in Los Angeles and Portland. However, furfural is produced only at Memphis and Cedar Rapids, Iowa.

Furfural, known chemically as an aldehyde, grew to industrial importance as a solvent. First produced in a German laboratory, it was once imported by the United States in minute quantities, at $1.50/ounce. Research by The Quaker Oats Co. made the chemical available commercially in 1922, at $2.50/lb. Today, however, improved production methods have brought the price down to a fraction of this price.

SAFETY—EVERY MAN'S OBLIGATION

The President's Conference on Industrial Safety and the U. S. Department of Labor have published a pamphlet on Labor-Management Cooperation for Safety.

The pamphlet details the principles approved by the Committee on Labor-Management Cooperation for Safety, and the Department of Labor has made a limited supply of extra copies available for distribution to companies interested.

The committee found that safety primarily is the legal and moral obligation of the employer, and the pamphlet gives several principles that should be followed.

For those in the chemical field who are cooperating with the Department of Agriculture's drive to reduce industrial accidents 50% by 1952, the publication contains a valuable summary of the philosophy of safety.

A. D. LITTLE CONTRACTS TO BUILD DRUG PLANT

Arthur D. Little, Inc., Cambridge, Mass., research and engineering organization, has contracted to design and construct a new pharmaceutical plant in Los Angeles for Riker Laboratories, Inc., a subsidiary of Rexall Drug Co. The new plant will produce Veriloid, a purified and standardized extract derived from Veratrum viride, used in treatment of hypertension. The crude botanical drug has long been known to be useful in reducing high blood pressure but has not previously been available in a satisfactory form.

Arthur D. Little, Inc., cooperated with Riker Laboratories, Inc., in the pilot plant stage of the development of the process and has designed the commercial plant, and will now procure equipment, supervise construction, installation, and start up the commercial plant.

A.A.A.S. TO MEET IN CLEVELAND

The 117th meeting of the American Association for the Advancement of Science, the annual meeting for the year 1950, will be held in Cleveland, Ohio, Dec. 26-30. Programs in every principal field of science from astronomy to zoology, are planned. All 17 of the Association's sections and subsections, and more than 40 participating societies and organizations, are completing plans for an aggregate of more than 200 sessions.

An extensive series of tours to mu-

seums, laboratories, and industrial plants of the Cleveland area has been planned. The Annual Science Exposition, in the arena of Cleveland's Public Auditorium, with some 150 booths, will be almost twice as large as that of the recent New York annual meeting.

For the engineers eight sessions are planned, joint separate programs with the Cleveland section of the A.S.M.E., the Cleveland Engineering Society, Case Institute of Technology, and a three-session symposium on Partnership of Industry and Science in Research.

C.A.R.E. NEEDS BOOKS FOR LOUVAIN LIBRARY

CARE UNESCO Book Fund recently made known its intention of channeling donations for recent books in English to fill some empty shelves of the Library of the University of Louvain in Belgium. This library was destroyed in World War I and though the building has been restored, shelves replaced and some books collected, the knowledge gained through American research and progress which continued during that war has not been made available to Louvain and other universities abroad. A bookplate inscribed with the name of the donor's organization will be inserted on all gifts of $10.00 or more.

On the walls of that library is the following inscription:

In Memory of the Engineers of the United States of America, who gave their lives in the service of their country and its Allies in the Great War 1914-1918. The Carillon and the Clock in this Tower have been given to the University of Louvain by members and friends of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, American Institute of Electrical Engineers, the Society of American Military Engineers, Army Ordnance Association, American Society of Naval Engineers, American Society of Consulting Engineers, American Institute of Chemical Engineers, American Railway Engineering Association, American Society of Heating and Ventilating Engineers, American Society of Refrigerating Engineers, Illuminating Engineering Society, Institute of Radio Engineers, Society of Automotive Engineers, Society of Naval Architects and Marine Engineers.

Flavel Barnes, advisor, book program, asks in a recent communication:

"Will you help your chimes (chimes given to Louvain by engineering associations following the first World War) to ring again over a library that so adequately serves northern Europe? The mantel of technical progress has been placed on our shoulders."

More information is available from Mr. Barnes and C.E.P. will be pleased to forward to him any communications our members might have.

CAST RESINS FOR PROCESS EQUIPMENT

Chemical process equipment, made of synthetic resins and designed for use under corrosive conditions is newly announced by the General Ceramics and Steatite Corp.

Trade named Kemplas, the new equipment is made of modified phenolic resins developed and produced by the Pennsylvania Salt Manufacturing Co. The resins are either cold-cast or laminated with glass cloth and molded into desired shapes. The new equipment is lightweight and yet stronger than construction materials normally used in such equipment.

On one corrosive application, General Ceramics reported that with a 60% hydrofluoric acid at elevated temperatures towers, pumps and miscellaneous fittings of Kemplas were used and after two years showed no trace of corrosive attack. In another case, pumps lined with Kemplas material handled a combination of sulfuric and hydrofluoric acid at 160° F. for 12 times as long as any special material previously used.

Cast pieces can be machined and threaded in the field and, during installation, can be joined to one another by cementing with the same resin as the parent pieces. Laminated pieces and equipment are used for situations requiring extra strength for support or under conditions of shock and can be field-cut by ordinary machine shop techniques. Flanging, and joining can be accomplished at the point of installation by using wrapped, cemented joints.

Kemplas resins are stable up to 370° F. and the recommended maximum operating temperature to afford a margin of safety is 350° F. The materials are resistant to virtually all acids except highly oxidizing acids. With certain modifications to the resin, equipment can be made up that will withstand definite concentrations of alkalies within certain temperature limitations.

INDIA SECTION ELECTROCHEMICAL FORMED

The India Section of the Electrochemical Society, Inc., was recently organized with headquarters at Bangalore. It is the first section to be formed outside the United States.

Officers of the section are: Chairman B. K. Ram Prasad, Vice-Chairman K. L. Ramaswamy who is a member of A.I.Ch.E. and J. Balachandra, and Secretary-Treasurer, T. L. Rama Char.

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LETTER TO THE EDITOR

HUMANIST AND ENGINEER

Sir:

I should like to express my gratification upon reading the *Opinion and Comment* by J. Henry Rushton in the August, 1950, issue of Chemical Engineering Progress. Dr. Rushton has expressed his conviction that engineering and humanism should not be divorced, but that, to the contrary, they should be "cross-fertilized." In particular, Dr. Rushton calls for application of the engineering viewpoint to the solution of social and legal problems. Since this view is entirely in accord with my own attitude, I must necessarily express my admiration for his keen insight into this important problem.

As one who has participated in a minor way in the development of the atomic bomb, it is my firm belief that engineers must shoulder their responsibilities toward society and humanity, and that they cannot in good conscience delegate these responsibilities to others. As engineers, we must realize that we have created materials, equipment, and production methods which can be an ever-increasing boon to mankind or which can be the means for effectuating a gigantic destruction of humanity and of civilization. It is imperative that we abandon the too-prevalent attitude of many, if not most, technologists that we are specialists, and that we should be satisfied to do our best in our own field, while leaving social and legal problems to others who are specialists in human relations. To do this is to relinquish our status as men and to become a part of the machinery we have created. It is to admit the impossible—that while others may be "humanists," we are "inhumanists," or at best "nonhumanists."

If it were altogether true that engineers are so specialized as to be incapable of contributing to the control of the society they have helped to create, it would not excuse us from our moral responsibilities. We must not put ourselves in a position similar to that of the German doctors during World War II, whereby they complacently performed sadistic and inhuman "experiments" on living people claiming that their activities were purely scientific and that any moral accountability should be charged to the politicians. We are responsible for what we do or what we fail to do, regardless of our desire to avoid liability. We cannot be amoral; we shall either be morally right or morally wrong. As engineers, we are interested in results. Is it not vital, therefore, that the work which we perform so capably and so thoroughly shall not be

MARGINAL NOTES

News of Books of Interest to Chemical Engineers

A Review Book Only

Industrial Instrumentation. Donald P. Eckman. John Wiley & Sons, New York, N. Y. 1950. 386 pp. $5.00.

Reviewed by H. U. Fisher, Control Engineer, Niagara Blower Co., New York, N. Y.

THE preface honestly states the purpose of this book to be a review of the principles used in various types of industrial instrumentation. The review is brief in each case, too brief in many instances and absolutely academic to the extent that neither advantages nor disadvantages are expressed. This is left entirely to the reader. In fact the reader, who is not experienced in the subject, would have a difficult time selecting instruments for a particular application.

The book is intended for undergraduates in engineering who have control problems to solve with reference to process work. It is not of particular interest to application engineers because most of them are familiar with the subject matter covered. An exception to this statement could be made regarding the first chapter. The author has done a good job in discussing the Qualities of Measurement, and to assist the application engineer in discussing his problems with a specialist in instrumentation, a great deal can be learned. Definitions of instrumentation terminology are good.

Chapters 2 through 10 cover the review of principles used in physical measurement and are too brief. Actually some of the chapters discuss subjects which require an entire volume, such as Chapter 6, Methods of Composition Analysis. In direct contrast Chapter 10 on Flowmetering is too long and deals with details most of which are of no interest to practical engineers.

Chapter 11, Process Instrumentation, is excellent. Most processing plant managers would profit by reading this chapter, and therefore, many of the operating superintendents and production engineers would also find information which would be useful to them. The purpose of a control center, when it is desirable and when it is not needed is discussed. Plant layouts referring to instrumentation, different methods of applying instruments and many similar problems are presented for the process design engineer, as well as other plant people.

The appendix seems to be of little value because most data are available in a more complete form somewhere else.

The instrument engineer has this information, and others are not particularly interested in it.

Perennial Question—Can Machines Think?

Giant Brains or Machines That Think. E. C. Berkeley. John Wiley & Sons, Inc., New York, N. Y. 270 pp. $4.00.

Reviewed by Don Lebell and W. C. Hurty, in charge of University of California's Los Angeles Campus Engineering Computing Facility.

IN this book Mr. Berkeley has attempted to supply information on computing devices to readers having varied backgrounds. While this is a worth-while goal it is a particularly difficult task to perform in a field as highly specialized and technical as that of computers.

Readers having experience with computers and mechanical computing methods may find Mr. Berkeley's book lacking in depth while the layman with no technical training will have considerable difficulty with parts of the book. It should be of greatest value to the reader with little or no previous knowledge of computers but with some broad technical background. To many people the presentation may seem immature because of the author's obvious efforts to achieve clarity and leave no point, however simple, unexplained. But, despite these objections the book will arouse considerable interest especially among that large group of lay readers who have little interest in the rigor of formal technical education but who are, nevertheless, fascinated by the advancing technology of the present day.

In addition to a discussion of the principles of a simple computer, punch-card machines, differential analyzers, IBM automatic sequence-controlled calculator, ENIAC, general purpose relay calculator, and a logical truth calculator, the text includes excursions into the types of problems computers may solve in the future, their possible effect on man, and their control by society.

Mr. Berkeley also delves into the question "can machines think?" Ultimately, this question can be answered only by careful consideration of one's definition of thinking. However, the author's viewpoint will evoke interest and stimulate the reader to think about these matters.

Variorum Edition on Elements

The Chemistry and Metallurgy of Miscellaneous Materials — Thermodynamics. Edited by Lawrence L. Quill. McGraw-Hill Book Co., Inc., New York. (1950) 329 pp. $3.00.

Reviewed by Ralph R. Wenner, Monsanto Chemical Co., Dayton, Ohio.

THIS book constitutes one of the series of volumes known as the "Plutonium Project Record" collected while developing methods for producing plutonium. It consists of ten papers by eleven authors dealing with the thermodynamic properties of elements and many inorganic compounds. The contents of these papers may best be judged by the following partial list of titles: "The Thermodynamic and Physical Properties of the Elements," "Thermodynamic and Physical Properties of Nitrides, Carbides, Sulfides, Silicides and Phosphides," "The Thermodynamic Properties of Common Gases," "The Thermodynamic Properties of the Halides," "The Thermodynamic Properties of Molybdenum and Tungsten Halides and the Use of These Metals as Refractories."

Sufficient descriptive material is provided in connection with the discussion of the data and the results of the equilibrium analyses to distinguish the book from a mere compilation of thermodynamic constants. Most of the recorded basic data have been compiled from previously available literature and a fair portion represents estimates made by the authors.

The average chemical engineer will find little to help or interest him in this volume. The engineer engaged in the inorganic process industries, metallurgical industries and atomic energy projects should find this set of data useful. The serious students of thermodynamics will want to add this book to his library as a convenient source of data and references to the original articles on the subject.

Prologue to Tomorrow. Robert Keith Leavitt. Pennsylvania Salt Manufacturing Co., Philadelphia, Pa. 100 pp.

THE Pennsylvania Salt Manufacturing Company reaches its one-hundredth year of organization during 1950 and to celebrate that event has issued the book, "Prologue to Tomorrow," a history of the company. Written by Robert Keith Leavitt, it is interesting reading, since the author has skillfully blended the commercial history of the company with background details—illustrations of what life was like, historical settings, etc.

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If you wish, a Johns-Manville Insulation Engineer will be glad to survey your equipment and make appropriate recommendations. For further details, send for a copy of folder IN-121A. Address Johns-Manville, Box 290, New York 16, N. Y.

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CANDIDATES FOR MEMBERSHIP IN A.I.Ch.E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E. which states:

Election to membership shall be by vote of the Council upon recommendation of the Committee on Admissions. The names of all applicants who have been approved as candidates by the Committee on Admissions, other than those of applicants for Student membership, shall be listed in an official publication of the Institute. If no objection is received in writing by the Secretary within thirty days after the mailing date of the publication, they may be declared elected by vote of Council. If an objection to the election of any candidate is received by the Secretary within the period specified, said objection shall be referred to the Committee on Admissions, which shall investigate the cause for such objection, holding all communications in confidence, and make recommendations to the Council regarding the candidate.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before *Nov. 15, 1950*, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st St., New York 17, N. Y.

APPLICANTS FOR ACTIVE MEMBERSHIP

Andrew Bagdasarian, *Rahway, N. J.*
Robert O. Brock, *East Chicago, Ind.*
Everett A. Bruce, *Paoli, Pa.*
William G. Burk, *Chicago, Ill.*
Paul Buthod, *Tulsa, Okla.*
Franklin S. Chance, Jr., *Knoxville, Tenn.*
Thomas P. Clarke, *Jersey City, N. J.*
J. M. Crockin, *Pittsburgh, Pa.*
Glen R. Davis, *Tulsa, Okla.*
George T. Deck, *Trona, Calif.*
Carroll J. Dobratz, *Pittsburg, Calif.*
Merten H. Douthitt, *Baltimore, Md.*
John B. Dwyer, *New York, N. Y.*
W. M. Gaylord, *Cleveland, Ohio*
William T. Griffiths, *Upper Darby, Pa.*
Raymond H. Hecht, *Sayreville, N. J.*
John K. Jacobs, *Cheltenham, Pa.*
Paul Kandell, *New York, N. Y.*
Ralph M. Knight, *Port Arthur, Tex.*
Charles E. Lieberman, *Houston, Tex.*
Thomas Liggett, III, *Beaver, Pa.*
James A. List, *Wilmington, Del.*
Leland Roy Lyons, *Fords, N. J.*
J. Emmett Maider, Jr., *Richland, Wash.*
William J. McNamara, *St. Paul, Minn.*
Byron E. Milner, *Philadelphia, Pa.*

Bartolomeo Orsoni, *Milano, Italy*
Glenn C. Putnam, *Orange, Tex.*
Milton H. Rau, *St. Louis, Mo.*
Cecil C. Rhodes, *East Lansing, Mich.*
Earl A. Schilt, *Buffalo, N. Y.*
Robert J. Schrader, *Kingsport, Tenn.*
William S. Sevier, *New York, N. Y.*
Ronald B. Smith, *New York, N. Y.*
Bernard J. Sullivan, *Rossford, Ohio*
Ralph A. Troupe, *Louisville, Ky.*
Frederic C. Tuttle, *Schenectady, N. Y.*
H. C. Ullum, *Institute, W. Va.*
Warren B. Warden, *Swarthmore, Pa.*
W. William Wiitanen, *Audubon, N. J.*
Robert S. Yates, *St. Louis, Mo.*
N. Emile Zachariah, *Kenosha, Wis.*

APPLICANTS FOR ASSOCIATE MEMBERSHIP

Joseph F. Campagnolo, *Baltimore, Md.*
E. S. Coddou, Jr., *Texas City, Tex.*
D. S. Saxena, *Delhi, India*
Leonard L. Taylor, *Carthage, Tex.*
Prospero Uy-Barreta, *Manila, Philippines*

APPLICANTS FOR JUNIOR MEMBERSHIP

Samuel L. Bean, *Auburn, Me.*

J. Brocoff, *New York, N. Y.*
Charles A. Burkart, *Columbus, Ohio*
Jack Carson, *Victoria, B. C., Canada*
Andrew J. Chase, *Orono, Me.*
William David Clark, *Thornton, Pa.*
Elmer William Coleman, Jr., *Erie, Pa.*
John H. Coleman, *St. Louis, Mo.*
Hubert J. Crouch, Jr., *Lincoln, Neb.*
Robert L. Cunningham, *Marblehead, Mass.*
John E. Cusack, Jr., *Westerly, R. I.*
John L. Denton, *Fort Wayne, Ind.*
R. E. Dugat, *Baytown, Tex.*
William U. Eberts, *Columbus, Ohio*
David E. Eddy, *Toledo, Ohio*
J. M. Farrar, Jr., *El Dorado, Ark.*
John J. Foster, *Elmhurst, N. Y.*
P. L. Fowler, *Blairmore (Alta.), Canada*
William J. Gartin, *Richland, Wash.*
William D. Gordon, *Lakewood, Ohio*
James Gretzinger, *Rochester, N. Y.*
John F. Hannan, *Manhasset, N. Y.*
Fred J. Hebert, *Baton Rouge, La.*
Richard C. Heininger, *Chicago, Ill.*
Roy W. Held, *St. Louis, Mo.*
G. J. Henrich, *Niagara Falls, N. Y.*
Burton F. Judson, *Richland, Wash.*
Ralph C. Kennon, *Baton Rouge, La.*

Ernest Knipp, Jr., *Houston, Tex.*
Walter C. Kohfeldt, *Baton Rouge, La.*
Stanley Kritzer, *Los Angeles, Calif.*
Philip G. McCullough, *Worcester, Mass.*
Joseph A. McDaniel, Jr., *Baton Rouge, La.*
Bob L. McFarland, *El Monte, Calif.*
Robert E. T. McMahon, *New York, N. Y.*
Frederic A. Obstfeld, *Akron, Ohio*
Walter R. O'Keefe, Jr., *Portland, Me.*
David W. Peat, *Cornwall, (Ont.), Canada*
Howard K. Rae, *Princeton, N. J.*
Frederick A. Richter, *Richmond, Me.*
Robert Ruffing, *Pittsburgh, Pa.*
Walter Sarvas, *Saco, Me.*
John A. Sauer, *St. Louis, Mo.*
John D. M. Shelly, *York, Pa.*
Leon Siedler, *Guatemala, C. A.*
Richard Sobel, *Claymont, Del.*
Frank Y. Staats, *Santa Monica, Calif.*
Joseph D. Stafford, Jr., *Wichita Falls, Tex.*
Morraine Elden Stangl, *Los Angeles, Calif.*
Salvatore S. Stivala, *New York, N. Y.*
Lloyd J. Svoboda, *Kansas City, Kan.*
William R. Taylor, *Cincinnati, Ohio*
Thomas E. Williams, *Harriston, Va.*
Robert Charles Wornick, *Brooklyn, N. Y.*
Robert N. Zabe, *Eastport, Me.*

SECRETARY'S REPORT

S. L. TYLER

THE Executive Committee of the Institute met Sept. 21 in the office of the Executive Secretary with all members in attendance.

The usual routine matters of approval of Minutes, receipt of Treasurer's Report, and approval of bills were taken care of promptly.

Applicants for membership, whose names were listed in the August, 1950, issue of *Chemical Engineering Progress*, were elected to the grade of membership indicated. Three resignations from membership were accepted.

The President reported the appointment of the Tellers Committee to count the nomination and election ballots as follows: L. P. Scoville, W. D. Kohlins, H. L. Malakoff, F. B. White.

Three new appointments were made to the Public Relations Committee at the request of J. H. Perry, Chairman. They were as follows: Randolph Antonsen, J. C. Whitwell, R. V. Greer.

The Secretary reported the receipt of a surplus from the Swampscott meeting of $179.15. It was received with thanks and it was voted that it be credited to the Institute Meetings Account.

The Institute had been invited to participate in the Centennial of Engineering which is to be held in Chicago in the summer of 1952 and was requested to appoint a local committee to work with the main committee on arrangements at Chicago. The committee consists of J. H. Rushton, Chairman, W. H. Congleton, G. Egloff, L. W. Faith, R. C. Gunness.

An invitation to send a representative to attend the inauguration of Marion Thomas Harrington as president of The Agricultural and Mechanical College of Texas was received and H. D. Wilde was appointed as representative.

A similar invitation was received from the Carnegie Institute of Technology for a representative to attend the inauguration of J. C. Warner as President. P. J. Curtis will represent the Institute.

D. O. Myatt was appointed representative of the Institute on the Subcommittee on Abbreviations to the ASA Committee Z-10, Letter Symbols and Abbreviations for Science and Engineering.

COLUMBUS MEETING

techniques, will be presented in two sessions on Wednesday, Dec. 6. Richard D. Hoak, Mellon Institute, will be in the chair.

Processing of Viscous Materials. As

Seated (left to right): J. A. Grant, Owens-Corning Fiberglas, Publicity; J. W. Clegg, Battelle Institute, Technical Program; W. B. Kay, Ohio State University, Technical Program. Standing (left to right): T. F. Lavery, Battelle Institute, Publicity, and A. Syverson, Ohio State University, Technical Program.

a simultaneous Wednesday morning session, this symposium will be guided by W. W. Kraft of the Lummus Co. Engineering experts will discuss such problems as mixing, pressure drop, and heat-transfer characteristics of numerous viscous materials. This subject will appeal to any engineer who has problems in handling viscous materials.

General Papers. An assortment of papers will be presented from Monday afternoon through Wednesday afternoon. Topics include hydrogenation of coal, drying, fluidized systems, filtration, heat transfer, and distillation equipment.

A paper, worth particular mention because of its universal appeal, will be given by Prof. Hoyt Sherman, Ohio State University. Rapid reading and perception methods, developed first for military trainees and aircraft spotters in World War II, will be presented to show how personal improvement might be made.

Aerial View of Battelle Institute.

LOCAL SECTION NEWS

CHEMICAL ENGINEERS CLUB OF WASHINGTON

The first meeting of the fall season was held Sept. 20 at the Roger Smith Hotel at which Thomas H. Chilton of the Du Pont Co. and Vice-President of A.I.Ch.E. spoke on "Units: Technical and Scientific."

A constitution and bylaws have been drafted for the club upon which the members have been asked to express their approval or disapproval.

The schedule for the coming year includes at least two symposia on (a) New Unit Processes and Operations, (b) Chemical Pest Control and possibly (c) Sulfur and Pyrites.

Reported by H. W. Yeagley

NEW YORK

Management Symposium

The inside story of how chemical enterprises are managed will be told to chemical engineers at a symposium to be sponsored by this Section Oct. 24, at the Hotel Statler in New York.

Functions of management will be explained by John E. McKean, president of Chas. Pfizer & Co., Inc. Robert L. Gibson, assistant general manager of General Electric Co.'s chemical department, will blueprint the organization of management. George B. Corless, executive development advisor for the Standard Oil Co. (New Jersey), will discuss executive development. William P. Witherow, president of Blaw-Knox Co., will discuss industrial relations.

Dinner speaker will be Robert E. Wilson, board chairman of Standard Oil Co. (Indiana), who will map a "Strategy for True Liberals." Toastmaster will be Donald B. Keyes, vice-president of Heyden Chemical Corp.

Symposium sessions will start at 2:00 P.M.; they will be held in the Penn Top of the Statler. Dinner will be at 7:00 P.M. in the Statler's Grand Ballroom.

For those who register, dinner will cost $6.00; for those not registering, dinner will be $7.00. In addition to the cost of the dinner, the registration fee for members of the New York and New Jersey Local Sections will be $2.00; for nonmembers the registration fee will be $3.00; for students, $1.00. Chairman of the symposium is Edgar L. Demarest, Buflovak equipment division of Blaw-Knox Co., 295 Madison Ave., New York 17, N. Y.

A meeting of this section was held Sept. 26 at the Brass Rail Restaurant, New York, with 50 members and guests present. T. H. Chilton, Vice-President of A.I.Ch.E., and technical director of development engineering division of the Du Pont Co., spoke on the subject, "Units."

Reported by R. L. Demmerle and J. A. O'Connor

SOUTHERN CALIFORNIA

This section held its monthly dinner Sept. 19, 1950, at the Rio Hondo Country Club in Los Angeles. Some 95 members and guests were present. C. N. Sjogren, director of research, C. F. Braun Co., was the guest speaker of the evening, and his subject was "Design for Inshell Heat Transfer."

Dr. Sjogren discussed the effects of

POWER DIVISION

CHEMICAL DIVISION
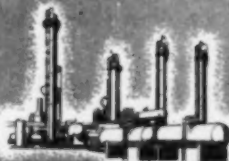
PETROLEUM DIVISION

NATURAL GAS DIVISION

Pictured above is a Pritchard designed plant recently completed for the separation of quality grade monochlor and dichlor benzene from crude chlorinated benzenes.

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LOCAL SECTION NEWS

(*Continued from page 30*)

design factors and manufacturing toler-
ances on the transfer rate and pressure
drop on the shell side of heat exchang-
ers. To illustrate the subject of his dis-
cussion, a technicolor movie was shown
of flow in full-size plastic heat-ex-
changer models. The models photo-
graphed utilized tinted water containing
aluminum powder, which gave a clear
and precise picture of flow patterns for
various types of exchanger construction.
The effects of several construction vari-
ables, such as cross-flow area, baffle-cut
area, and baffle-tube clearance on trans-
fer rate and pressure drop were mathe-
matically correlated and illustrated by
slides.

Reported by William J. Baral

NORTHERN CALIFORNIA

This section will hold a regular meet-
ing Nov. 6 at the Engineers Club in San
Francisco. The speaker will be Max
Spealman, production manager of the
San Francisco division, Stauffer Chem-
ical Co. Dr. Spealman's subject will be
the manufacture of sulfuric acid.

The section held a special joint meet-
ing with the local section of the National
Association of Corrosion Engineers
Sept. 15. At the meeting and dinner,
held in San Francisco at the Engineers
Club, Prof. Mars G. Fontana, Ohio
State University, and a member of
A.I.Ch.E., spoke on "Corrosion Resis-
tance of Stainless Steel," and discussed
several theories relative to the subject.
There was a total attendance of 80.

Reported by J. V. Hightower

DETROIT JUNIOR GROUP

This group held its first meeting of
the 1950-51 season Sept. 13 in the Junior
Room of the Rackham Memorial.

William G. Fredrick, director of the
Detroit Bureau of Industrial Hygiene,
presented a talk entitled, "Industrial
Hygiene." Following his outline of the
history of industrial hygiene in the De-
troit area as well as in the United States,
he discussed the more common occupa-
tional diseases, especially those in the
chemical industry.

Officers for the 1950-51 season are:

Chairman—W. J. Leisten, Wyandotte
Chemicals Corp.
Vice-Chairman—W. Jones, Detroit
Sulphite Pulp and Paper Co.
Secretary-Treasurer—Robert E. Cav-
anaugh, Sno-Flake Products Co.
Program Chairman—Joseph Adinoff,
Parke-Davis & Co.
Membership Chairman—P. J. Bonnell,
U. S. Rubber Co.

Reported by W. W. Jones

SOUTH TEXAS

Fifth Annual Technical Meeting

Petroleum-derived starting materials for the flourishing Gulf Coast chemical industries will be discussed in several papers to be presented at the Fifth Annual Technical Meeting of this section to be held Oct. 27 at the Galvez Hotel, Galveston, Tex.

At the evening banquet of which Cal Dickinson, Diamond Alkali Co., Houston, is master of ceremonies, Warren L. McCabe, President, A.I.Ch.E., will be the principal speaker. His topic is "Chemical Engineering—1950 Model." Welcoming addresses at the different sessions will be given by W. A. Cunningham, chairman of the South Texas Section and by James A. Lee, Southwest editor of Chemical Engineering, a McGraw-Hill publication. There will be a student session entitled "Opportunities for Young Chemical Engineering Graduates."

The general chairman for the technical meeting is C. L. Dickinson. Assisting him are John McKetta, Austin; Don Schroeter, Texas City; V. L. Keldsen, W. T. Richard, and Jack McLellan, Houston.

The following list of papers is scheduled for presentation:

PROGRAM

Morning Program

TECHNICAL SESSIONS

Session A—Ball Room, Frank Spuhler, Humble Oil & Refining Co., Presiding.

The Production of Ethylene for Chemical Synthesis—*N. L. Foskett, Stone and Webster Co., Boston, Mass.*

Butylene.—*Speaker from Humble Oil & Refining Co.*

The Electric Discharge—A New Chemical Engineering Tool—*E. P. Schoch, University of Texas, Austin, Tex.*

Session B—Terrace Room, Joe Young, Infilco Corp., Presiding.

Heat-Exchange Movie — Design for Shellside Heat Transfer—*W. W. Blake, C. F. Braun and Co., Houston, Tex.*

Use of Sea Water as a Cooling Medium on the Gulf Coast—*August H. Meinrath and Tom S. Moffatt, Southern Alkali Co., Corpus Christi, Tex.*

Handling of a Typical Labor Case—*T. M. Davis of Baker, Botts, Andrews, and Parish, Houston.*

Afternoon Program

Session C—Ball Room, Neil H. McKay, Shell Chemical Co., Presiding.

The Use of Radioactive Isotopes in Industry—*L. O. Morgan, University of Texas.*

Road Octane Studies—*Speaker from Du Pont Co.*

Platforming—*Vladimir Haensel, Universal Oil Products Co.*

Effective Technical Group Speaking.

STUDENT SESSION

Session D—Terrace Room, John J.

Technical Topics

WELDING STAINLESS ALLOYS

Norman S. Mott
Chief Chemist and Metallurgist
The Cooper Alloy Foundry Co.

In the welding of stainless alloys, four types of composition have to be taken into consideration—the hardenable martensitic straight chromium group; the non-hardenable ferritic straight chromium group; the corrosion resisting chromium-nickel group, and the heat resisting chromium-nickel group. These alloy compositions have, in varying degrees, greater thermal expansion and lower thermal conductivity than carbon steels, and in some instances have carbide mannerisms which affect corrosion resistance.

When the torch flame or arc is applied, the metal is heated to a very high temperature only in the area being welded. The heated metal expands and tends to push out in various directions against the colder surrounding metal, producing severe internal stresses. When the heat source is removed, the resultant contraction produces pulling stresses acting between the cooling and the cold metal. If the metal does not have sufficient ductility to stretch and accommodate itself to these great stresses, cracking will result. This is most prevalent in the lower ductility straight chromium grades. By making temperature gradients as gradual as possible, this danger can be minimized.

In the chromium-nickel corrosion resisting alloy types, a form of grain boundary carbide precipitation occurs during welding. To offset the dangers of intergranular corrosion, these carbides must be put into solution by subsequent heat treatment before the welded metal is put into use.

Difficulties which are involved in welding cast stainless steel can be overcome through the use of pre-welding and post-welding thermal treatments as indicated below. Alloys for heat resistance applications usually do not require any thermal treatment after welding.

ALLOY	REMARKS
5%Cr	Preheat to 400° F. or over. After welding, cool to not less than 300° F. then heat to 1650°F....hold for 1 hour, furnace cool to 1350° F., hold for 2 hours, then air cool.
9%Cr	Preheat to 400°F. or over. After welding, cool to not less than 300° F. then heat to 1350° F....hold for 2 hours, then air cool.
12%Cr	Preheat to 400° F. or over. After welding, cool to not less than 300° F. then heat to 1350° F....hold for 4 hours, then air cool.
16%Cr	Preheat to 250-300°F. After welding, cool to 250° F. or lower, then heat to 1450° F....hold for 4 hours, then air cool.
18%Cr	Preheat to 250-300° F. After welding, cool to 150° F. or lower, then heat to 1450° F....hold for 4 hours, then air cool.
27%Cr	Preheat to 250° F. or over. After welding, heat to 1650° F....hold for 2 hours, then rapidly air cool. If distortion is feared stress-relieve weld for 1 hour at 1350° F. followed by air cooling.
18-8S	Preheat not required. After welding heat at 2000° F. for 1 hour, then water quench.
18-8SCb	Preheat not required, nor is post heat. However, after welding, it may be stress relieved at 1650° F. for 2 hours followed by air cooling.
18-8SMo	Preheat not required. After welding heat at 2000° F. for 1 hour, then water quench. Sufficiently ferritic alloys can often be used without post heating.
FA-20	Preheat to 400° F. After welding cool very slowly then heat to 2000° F....hold for 1 hour and water quench.

BULLETINS

1 • WATER TREATMENT. An illustrated 12-page guide to water treatment, by the Elgin Softener Corp. Explains the need for water treatment, discusses the prevention of scale and corrosion, treatment of boiler water, and tells of various treatments which prevent difficulties occurring with untreated water.

2 • INDUSTRIAL SCREENS. For all users of screens in industry, the Bixby-Zimmer Engineering Co. has a new bulletin on its product which features round-rod construction of screens. Advantages of this are listed and also descriptions of various kinds of screens, mountings, equipment, etc. Vibrating screens, shaker, centrifugal, conveyor, heat driers, etc., are all described.

3 • CORROSION - PROOF CEMENT. A bulletin on corrosion-proof cements, in which information is compiled in a chart to help select the correct cement for specific applications, is offered by The Atlas Mineral Products Co. Covers resin, sulfur, silicate and asphaltic cements.

4 • 5 • 6 • 7 • SPEED REDUCERS. For the engineer with a speed reducer problem, The Falk Corp. has published four bulletins. All follow the same editorial pattern. Methods of selection of speed reducers, hp. rating tables, torque capacity, overhung load capacities, dimensions, backstops, flexible couplings, etc. Each bulletin covers a different type. (4) The parallel shaft roller bearing speed reducer; (5) the parallel shaft speed reducer with sleeve bearings; (6) horizontal right-angle speed reducer; (7) vertical right-angle speed reducer. Gives examples of the methods of determining the correct speed reducer to use in any particular installation.

8 • CHEMICAL FEEDER. Three sizes of a universal chemical feeder, with feeding ranges of from 1 to 5000 lb./hr. is the subject of a new bulletin by Omega Machine Co. Accuracy is within 1% by volume, stroke of feed is adjustable, dustproof, has a dissolving chamber, hydraulic jet mixers, etc. Details of construction, operation, how automatic controls are attached, how platform scales are tied in with the operation, etc., are all explained.

10 • PUMP SEQUENCE CONTROLLER. For bulk station and loading operators, in petroleum and chemical plants, Fischer & Porter Co. have a new 4-page publication of their application engineering department, explaining a new pump sequence controller. It starts and stops pumps automatically as the flow demand changes. Electronic circuit actuated by a flow meter located in the main pump header. Any number of pumps may be tied to the circuit. Flows of from 1/2 to 6000 gal./min.

11 • AGITATING AND MIXING EQUIPMENT. A new catalog showing portable power mixers, agitator-mixer assemblies, drives, side-entering agitators, acid-resistant linings, etc., of The Patterson Foundry & Machine Co. Each agitator gives specifications, drawings, propeller size, metals in which it is available, etc. Shows typical installations.

14 • CONTROL OF ALGAE. The Dow Chemical Co. offers a report of the experiments and results at one of its plants on the addition of bromine to control algae and slime in water-cooling towers.

15 • FIRE FIGHTING. Ansul Chemical Co. offers an educational booklet on the fundamentals of fire extinguishing. Four-page illustrated discussion of what fire is, causes of fire, and proper methods of extinguishing.

16 • DEEP-WELL TURBINE PUMPS. The Deming Co. has a new 20-page booklet giving construction details, various types of drive and typical installations of deep-well turbine pumps. Used in the fuel oil, gasoline, sump, boiler feed water, etc., applications. Bulletin gives the construction details such as the collar and shaft, bowl assembly, and goes into considerable explanation of the whole pump assembly.

17 • STAINLESS STEEL VALVE. A complete 48-page catalog on stainless steel valves, fittings and accessories is offered by The Cooper Alloy Foundry Co. Contains engineering drawings, weights, dimensions, size ranges, materials, corrosion data, nomenclature and design information. Covers nickel, Monel, all the types of valves and many of the other fittings that are used in corrosion-resistant installations.

Mail card for more data ▶

18 • TUNGSTEN AND MOLYBDENUM. A manual on tungsten and molybdenum, published by Fansteel Metallurgical Corp. The book, well illustrated and written, covers the powder metallurgy techniques used in molybdenum and tungsten, gives the typical properties of both metals —mechanical and chemical, the uses and applications of the metal and the available forms. Gives something on fabricating techniques and the engineering services of the company.

19 • FILTER AID. A high absorbent lignocellulose for use as a filter aid, a dry carrier for oily or aqueous liquids, a conditioner for solids subject to caking and a protein denaturant, is a new product of the Masonite Corp. Bulletin gives description of the product including typical physical analysis, chemical analysis, some ideas as to its use and application, shipping information, etc.

20 • MILLS AND MIXERS. A general catalog on the line of roller mills, colloid mills and mixers made by the process machinery division of the Troy Engine and Machine Co. Describes a high speed, one-point adjustment mill and others. Features an angular mixer with an angular power-tilting device and three zone mixing through a revolving tank and moving mixing element.

22 • PRESSURE BLOWER. The Moore Co. with a new descriptive bulletin on Class 2000 axial flow pressure blowers. Bulletin covers engineering data. The 2000 units may be assembled from standard parts from 2 to 9 blades for any unit of given diameter. Another feature is that the rotor is permanently greased with silicone grease. Volumes up to 100,000 cu.ft./min., and pressures up to 4 in. of water. Bulletin has complete descriptions showing cutaway views of drive units. Describes belt drive units, gives data on performances for a number of the blowers, data on construction, engineering drawings, with dimensions.

23 • PRESSURE AND TEMPERATURE REGULATORS. A 32-page booklet about pilot-operated pressure and temperature regulators made by the Spence Engineering Co., Inc., In addition the booklet covers strainers, thermostats, desuperheaters, flange standards, etc. Tables of steam capacity and flow, regulated valve sizes for air flow, etc.

24 • CHEMICAL ENGINEERING NOTATIONS. The publishers of *Chemical Engineering Progress* have a one-page insert, suitable for looseleaf notebooks, which gives the standard notations and abbreviations for chemical engineering. It is a condensation of the American Standards Association "Letter Symbols for Chemical Engineers" which includes also proper abbreviations.

EQUIPMENT

25 • TYGON TUBING. Tygon plastic tubing of The U. S. Stoneware Co. is now available in large sizes ranging from $1\frac{3}{4}$ in. to $2\frac{1}{2}$ in. in diameter. Tygon is translucent and is used in bulk handling of liquid food products, drugs, chemicals, etc. Can be steam-sterilized and its flexibility permits it to make bends with a minimum of waste space.

26 • PLASTICIZING PAN. The Patterson Foundry & Machine Co. has newly placed on the market a new plasticizing pan for the phosphate fertilizer industry. Built in sizes up to 10 ft. the crushed fertilizer rock is fed continuously to the machine which reduces it, and also mixes it with added liquid. After plasticizing discharge is through the bottom for drying. Mixing and plasticizing is by stages with the feed entering the center and traveling to another chamber where the plasticizing is completed.

27 • POLISHING FILTER. A new polishing filter by the Sparkler Manufacturing Co. uses a horizontal plate principle, a prefabricating medium and diatomaceous filter aid. These are arranged so that filter quality does not fall off toward the end of the filtration cycle. Air pockets are eliminated and plates are bolted together in the form of a cartridge which enables them to be removed for cleaning. Made of Everdur, can be designed for working pressures up to 100 lb./sq. in.

28 • AUTOMATIC BUNSEN BURNER. For laboratories using Bunsen burners intermittently, Hanau Engineering Co., Inc., has devised a new automatic unit that flames only

when needed. It is controlled by touch. Can be regulated for a continuous flame.

29 • CAUSTIC-CHLORINE MACHINE.
For the industry that requires small quantities of caustic soda and chlorine, Amroc, Inc., developed a new, special electrolytic plant for production from brine. Requires a space 3½ ft. by 25 ft. and consists of a mercury cell complete with denuder, power rectifier, brine-preparation tanks, recirculation equipment, caustic receiving tank, etc. The 24-hour output of the plant will be 225 lb. of 100% caustic, 200 lb. of chlorine and 5 lb. of hydrogen. Equipment can be installed to produce hypochlorites or hydrochloric acid. Automatically controlled and designed for the specific installation.

30 • FILTER UNIT. Titeflex, Inc., has a new stainless steel filter chamber in two sizes, one having filter areas of 10 sq. ft., the other of 20 sq. ft. Has a precoat tank and chambers are so fixed that they can be operated simultaneously with the precoat tank, or singly. Has a backwash system which enables the filter to be cleaned without labor. Catalog available.

31 • BALL MILL. A new Tricone ball mill for wet and dry grinding and pulverizing applications, by the Hardinge Co., Inc. The new feature of the mill is a slightly tapered shape which keeps the larger grinding balls at the feed end of the mill. Provides room for additional smaller grinding media at the discharge end.

32 • LONG-SWEEP ANGLE VALVE.
Hammel-Dahl Co. announces a new long-sweep angle valve which is designed primarily to produce a minimum turbulence in flow through the valve. For use on slurries or other solids in suspension which tend to plug conventional valves. The valve plug is streamlined and the seat is designed as a section of the venturi throat. Bodies can be

supplied in carbon, steel or stainless steel.

33 • ROOF VENTILATOR. American Machine and Metals, Inc., are in production with a new portable discharge roof ventilator for industry. Motor driven and available in diameters 36 in. to 48 in. with capacities up to 41,000 cu. ft. of air/min.

34 • DISSOLVER. For use on works batches of from 5 to 100 gal., The Cowles Co., Inc., has a new dissolver for use on material ranging in viscosity from 1 to 30,000 cps. The assembly, motor, bridge, and dissolver unit can be adjusted in height through a range of 11 in. by an elevating screw. The impeller is removed quickly since the bridge support, etc., can be tilted to an angle of 60°. Driven by a 5-hp. motor, through a belt drive. Specially designed impellers are available.

35 • EMERGENCY PUMP. A general utility pump which operates completely submerged, for removal of water from pits, tanks, vats and depressions in industrial plants, is new with Kenco, Inc. Operated either automatically by a liquid level switch, or manually by a cord switch, it may be used in any depth of water and will turn off automatic-

ally when it draws air. Water can be drained to within ⅛ in. of the floor. Liquid-level switch operated by air pressure created when water rises around the switch and traps air within the skirt. Special installations for high turn-on requirements.

36 • KEMPLAS. A new line of chemical process equipment made from modified phenolic resins and designed to meet corrosive conditions, is in manufacture by the General Ceramic & Steatite Corp., the resins being produced by the Pennsylvania Salt Mfg. Co. Tests of the material, using 60% hydrofluoric acid showed that towers, pumps and fittings were operating with no trace of corrosive attack after two years. The resins may be cold-cast or laminated with glass cloth and then molded. Cast resins are used for pump volutes, impellers, fittings, and may be machined and threaded. Laminated resin has strength and shock resistance and is used to make tanks and pumps. Resins are stable up to 370° F. and are resistant to virtually all acids. Full line of equipment is now being manufactured.

37 • SIGMAMOTOR. A pumping unit which makes use of pressure exerted by a series of "fingers" on flexible tubing, is the idea behind a device called Sigmamotor pro-

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Cards valid for only six months after date of issue

Chemical Engineering Progress Data Service

I would like to obtain more information on the items represented by the numbers I have circled.

1	2	3	4	5	6	7	8	10	11	14	15	16	17	18	19
20	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
37	38	39	40	41	46	47	48	49	50	51	52	53			

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Name _____ Position _____

Company _____

Address _____

City _____ Zone ____ State ____

duced by E. & M. Enterprises, Inc. Designed primarily as a laboratory or pilot plant tool, the fluids in flexible tubing receive a propulsive force from a series of fingers pressing against the tubing in sequence. Either liquids or gases can be pumped. The unit will handle from $1\frac{1}{2}$ to 30 gal./hr., with tubing varying from 3/16 in. to $\frac{1}{4}$ in. in diameter.

38 • CHECK VALVE. Leakproof check valves in sizes from $\frac{1}{8}$ in. to 1 in., poppet type with an "O" ring seal, are being offered by James-Pond-Clark. The valves are available in any material. Buna-N seals. Working pressures are from 0 to 3000 lb./sq. in. and temperatures of from $-65°$ to $280°$ F. Other low pressure types are available from 0 to 1 lb./sq. in. On order, valves to withstand temperatures up to $500°$ F. Data sheet giving the pressure differentials, sizes, etc., available.

39 • PNEUMATIC CONVEYOR. A pneumatic conveyor system for bulk materials is announced by the Crane Co. Called Turbo-Drive, it is available in three sizes—7-, 15-, and 30-cu. ft. capacities. The Crane Co. has used these systems in its own plants. Used primarily for moving sand in foundries, the system uses air pressure of from 40 to 60 lb./sq. in. and 1 cu. ft. of air will deliver 3 to 4 lb. of sand.

40 • SWIVEL MIXER BRACKET. An adjustable swivel mixer mounting bracket for any type mixer, which gives rapid adjustment to any desired mixing position and having a self-contained locking device, is a new product of the Alsop Engineering Corp. The bracket clamps tankside and can be permanently at-

tached to open tanks of from 5- to 300-gal. capacity.

41 • STEEL-BELT CONVEYORS. For handling foods, chemicals, bakery products, etc., Sandvik Steel, Inc., has issued a bulletin describing its steel belt conveyors. Either carbon or stainless steel, with flat or troughed belts, with or without cooling. Standard sizes from widths of 8 in. up to 16 in. The bulletin shows many features including a patented water bed conveyor. It was incorrectly reported in the August Data Service (36) that sizes of these belts run up to 16 in. Widths run up to 32 in. and wider belts are available composed of two or more longitudinally joined bands.

CHEMICALS

46 • ACETONITRILE. A bulletin on acetonitrile from the Niacet chemicals division of the United States Vanadium Corp. Used in synthesis of organic compounds. Bulletin gives physical and chemical properties, specifications, shipping and handling information, chemistry, and uses. Information as a reactant, and extraction solvent for fatty acids. Points out that for each fatty acid there is a temperature above which acetonitrile is infinitely soluble, and below which, its solubility is low. Fatty acids can be precipitated out by a slowly cooling solution of acetonitrile.

47 • ACTIVATED CARBON. Pittsburgh Coke & Chemical Co. offers a 10-page booklet on vapor and liquid phase adsorbent applications of granular and pulverized activated carbons. Gives typical uses and gives also, something on production and

research. Pittsburgh Coke & Chemical Co. makes the carbon from bituminous coal and process is briefly illustrated.

48 • N_2 FOR IMPACT PULVERIZING. For better, more rapid, and effective pulverization, The Linde Air Products Co. has a method of using liquid nitrogen in spray form to cool material rapidly to a point of maximum fragility before it is ground in mills. The amount of energy necessary to reduce the material for fracture is decreased and efficiency is such that the new process will accelerate high-speed pulverization of tough and heat-sensitive materials. Saran and polystyrene, hard materials to pulverize, are being successfully ground by this method. Liquid nitrogen has a temperature of $-320°$ F.

49 • CHEMICALS FROM COAL. Koppers Co., Inc., in a 44-page bulletin describes 58 commodity and specialty chemicals recovered in the coking of coal. Data sheets in the book give physical and chemical properties, suggested uses, structure, etc.

50 • DIMETHYL CHLOROACETAL. A data bulletin describing dimethyl chloroacetal used in synthesis of chloroacetaldehyde, sulfa drugs and other pharmaceuticals, is available from the General Aniline & Film Corp.

51 • CELANESE SOLVENTS. A revised bulletin of the chemical division of Celanese Corp. of America, on nitrocellulose solvents made by the company. The data sheet describes the formulation of two solvents, gives base lacquer studies, formulations, etc.

52 • SYNTHETICS. The 1951 edition of the book, "Physical Properties of Synthetic Organic Chemicals," a 16-page condensed guide for applications and physical properties of more than 250 synthetic organic chemicals, is off the press, Carbide & Carbon chemicals division.

53 • ALKYL PHENOLS. A mixture of monoalkyl phenols predominantly parasubstituted, is offered by the Jefferson Chemical Co., Inc. Suggested for use as a nonionic detergent intermediate, in the manufacture of lubricating oil additives, and in the preparation of various resins and plasticizers. The company is offering a technical bulletin explaining the physical and chemical properties and suggested uses.

LETTER TO THE EDITOR

utterly destroyed by social pressures which we have not deigned to consider?

If it were altogether true that we are so specialized as to be incapable of contributing to the regulation of society, it would not excuse us; instead it would require us to mitigate this condition. However, it is not at all true that we are unable to contribute anything in the field of social relations. As pointed out by Dr. Rushton, we have the engineering outlook to contribute, and this is the most successful method of achieving *results* which has yet been devised. As a member of both the legal and engineering professions, I can personally vouch for the fact that the engineering viewpoint is admirably adapted to the analysis of social and legal problems. It has been clearly demonstrated in the law school of my university that students with engineering backgrounds do much better in law school than those students who have a liberal arts background. The reason for this is that engineers have been trained to analyze problems, to separate the nonessentials, and to balance the conflicting forces in such a way as to achieve the optimum result. As has been said by a profound legal scholar, Dean Roscoe Pound, law is "social engineering." That is to say, it is the attempt to find methods of accomplishing the optimum social result. If the humanists can be made to understand the engineering viewpoint, whereby vested interests in theories are not tenable merely upon a show of authority, whereby dogmatism is defeated by rationality and where logical analysis and synthesis replace exhaustive verbiage, then engineers can indeed make an important contribution in social relations.

It is not enough, however, for engineers to teach their philosophy to the social engineers. Our humanities experts also suffer from an abysmal ignorance of the physical aspects of the world we live in. Many important social issues are intertwined with technological complexities. For example, the legal control of atomic energy is indeed difficult in view of the too-prevalent views of some legislators that atoms are inherently dangerous or that uranium (without further description) is likely to blow up at any time. Examples can be multiplied endlessly. It is important to realize that the failure of humanists to understand the basic elements of science or the underlying philosophy of engineering has contributed to their inability to extricate themselves from social dilemmas as fast as the technologists can create them.

It should not be supposed, however, that engineers are at present in a position to enter directly into the solution of social problems as to achieve startling results. Just as the "social engineers" are ignorant about technology, so too are the engineers largely ignorant in the field of social relations. Logical analysis and synthesis based on ignorance of the facts is undoubtedly even worse than the present methods of social science. Engineers, flush with their successes and accomplishments in their own field, and convinced of their ability to "see through a problem," are all too prone to reason from ignorance of social problems. Not only are their premises inarticulate—they are also unconsidered. Engineers must begin to look at social problems in the same way as they view technical problems. First they must get the facts, then they must analyze the problem, and then they must attempt to balance the conflicting forces so as to achieve the socially desirable result. When they deal in social relations, engineers must not speak from ignorance; they must not adopt authoritarian and arbitrary methods. They should seek to apply the rational methods they use in their own field to social problems. If they can do this, they can make as great a contribution to the solution as they have to the creation of social problems.

Sept. 11, 1950

Melvin Nord,
Detroit, Michigan

78 APPLY FOR QUALIFICATION CERTIFICATE

The Committee on the National Bureau of Engineering Registration has accepted 78 new applications for Certificate of Qualification during the period from July 1, 1949, to June 30, 1950. With 11 pending from the previous year the total reaches 89. Of the 89 applicants, 70 were approved, 2 rejected and 17 were pending on June 30. As of June 30, 1950, the total number of Certificates of Qualification issued by the National Bureau of Engineering Registration was 1246.

COLUMBUS MEETING

Plant Trips

One of the more fascinating prospects of the meeting is the Plant Trips Program, because it affords otherwise unobtainable opportunity to visit varied industries, many nationally known. The schedule for the Columbus meeting comprises 29 plants and businesses in the area. These are listed here together with principal products or activities; descriptive detail on many of them will be published in the November issue of *Chemical Engineering Progress*.

Plants participating are as follows:

Battelle Memorial Institute—industrial research
Capital City Products Co.—hydrogenated oil products for food industries
Columbus Water Works—50,000,000 gal./day modern softening plant
Edward Orton, Jr., Ceramic Foundation—pyrometric cones, ceramic research
Dean and Barry Co.—paints, varnishes, lacquers
M & R Dietetic Laboratories—ice cream mixes, baby foods, and lactose
Exact Weight Scale Co.—industrial scales
Jeffrey Manufacturing Co.—chemical process and mining equipment
Ironsides Co.—phenolic resins, asphaltic coverings, industrial lubricants
Pure Oil Co., Newark, Ohio—refining of crude oil
Smith Agriculture Chemical Co.—sulfuric acid, fertilizer
Surface Combustion Corp.—gas-heating equipment
Ternstedt Division, General Motors—automobile trim and hardware
Timken Roller Bearing Co.—roller bearings
Farmers Fertilizer Co.—sulfuric acid (Mills-Packard Towers)
Sewage Treatment Works, City of Columbus—60,000,000 gal./day treatment
Buckeye Steel Castings Co.—heavy steel castings
The Franklin Brewing Co.—brewing
Ohio State University—chemical engineering department—Cryogenics Laboratory, cyclotron
American Zinc Oxide Co.—zinc oxide products
Mead Paper Co., Chillicothe, Ohio—manufacturer of paper, production of lignin
Owens-Corning Fiberglas Corp., Newark, Ohio—fibrous glass products
Washington Breweries—brewing
August Wagner Breweries, Inc.—brewing
D. L. Auld—automobile emblems and accessories
Marblecliff Quarries—limestone, lime
Ranco, Inc.—thermostatic controls
Yardley Plastics Co.—plastic products and piping
Sewage Treatment Works, City of Delaware—modern plant for a city of 10,000

Entertainment

Sunday evening, Dec. 3, will afford opportunity for early comers to see their old friends and to make new ones at the convivial get-togethers. This event will be in the Junior Ball Room of the Neil House. Dress informal.

The Welcome Luncheon on Monday, Dec. 4, will see an innovation in the serving of a light but adequate meal

MINNEAPOLIS MEETING

E. L. Mongan, Univ. of Cincinnati, and
J. J. Gorman, Rohm & Haas.

omy." Its title described the significance
of population trends toward projecting
future economic conditions. The num-
ber of women of marriageable age at
any time in the population is important
in predicting the relative demand for
consumer goods. They are also impor-
tant since they produce the future gen-
erations. The number of women in the
19-to-24-age group is currently at its
cyclic minimum but will again reach a
maximum in 1960, Dr. Souders esti-
mates, and will bring with it an era
of prosperity.

R. Upgren, University of Minnesota,
presented in understandable terms the
position that money holds in our econ-
omy. His paper, "The Stoichiometry of
Money," indicated two methods which
might be used to finance the large Gov-
ernment expenditures currently being
made. One of these could be a pay-as-
you-go plan with taxation as the means
of raising funds; the alternative and
inflationary method would involve bor-
rowing by the Government from the
Federal Reserve banks.

Two other symposia were entitled,
"Indoor vs. Outdoor Chemical Plant
Construction," and "Chemical Engi-
neering in the Food Industries." All the
papers presented in the chemical plant
construction symposium were in favor
of the outdoor plant. The points pre-
sented in favor of the outdoor plant

N. H. Ceaglske and R. F. Hein, Uni-
versity of Minnesota.

World's Largest Natural Gas Compressor Station, Sugar Grove, Ohio.

COLUMBUS MEETING
(*Continued from page* 38)

consisting of soup or fruit cup, sandwich, pie, and a beverage, at a nominal price. Dubbed "Soup 'n' Sandwich Luncheon," the standardized menu will make possible rapid service of an appetizing luncheon.

Events of the Central Ohio Party, Monday evening, Dec. 4, are: dinner, concert by the Ohio State University Symphonic Choir of 60 fine student voices, and an informal get-together. Directed since its founding in 1937 by Prof. Louis H. Diercks, composer and teacher, the choir is well known for its beautiful performances and promises a rare treat.

Ladies' Program

A tour of Greater Columbus has been arranged for Monday, Dec. 4, which includes the Omar Bakery, Art Museum, luncheon at Scioto Country Club, and tea in Sessions Room. In the evening is the Ohio Party—dress optional.

The ladies will pay a visit Tuesday, Dec. 5, to the A. H. Heisey Co.'s plant at Newark, maker of fine glassware, see the historical Indian mounds, lunch at Granville Inn, and hear a lecture on the Hopewell Indian Culture. In the afternoon, the ladies will be guests of Mrs. Games Slayter at her home for tea. Dress is optional for the Awards Banquet in the evening.

Wednesday morning, Dec. 6, has been left open for shopping. Luncheon will be at the Maramor, famous Central Ohio restaurant, followed by a fashion show and bridge party.

Information Center

A well-staffed information center will be maintained on the mezzanine floor of the Neil House to answer queries on restaurants, hotels, program arrangements, local attractions, and transportation.

MINNEAPOLIS MEETING
(*Continued from page* 39)

were strong and some of the advantages are (1) elimination of building costs, (2) increased safety features because of inability of toxic or hazardous vapors to accumluate, and (3) less crowded equipment spacing allowing easier equipment maintenance including use of mobile cranes for the removal and replacement of heavy equipment. This symposium was planned by J. R. Minevitch, E. B. Badger & Co.

W. L. Faith, Corn Products Refining Co., organized the food industry symposium. One of the interesting papers in this symposium was entitled "Chemical Engineering in the Frozen Food Industry," by V. C. Praschan, Clinton Foods, Inc. Mr. Praschan discussed the concentration and freezing of orange juice and described methods in current practice. In most of the evaporating systems described by Mr. Praschan, some type of vapor recompression scheme was used in addition to a multiple-effect system employing backward feed.

T. Baron, Univ. Illinois, received award for best-presented paper.

M. C. Molstad, Univ. of Pennsylvania, and Mr. and Mrs. W. A. Carlson at the buffet supper which was given Tuesday evening.

Paper Presentation Award

T. Baron, University of Illinois, was judged as having given the best presentation of any paper at the meeting. Mr. Baron who participated in the Reaction Kinetics Symposium was the author of the paper "Generalized Graphical Method for the Design of Fixed-Bed Catalytic Reactors." Honorable mention in this connection went to Arthur E. Lindroos for presentation of the paper "Phase Equilibria in the System Nitrogen-Ammonia at High Pressures" by A. E. Lindroos and B. F. Dodge of Yale University, and to R. A. Buckley for his presentation of the paper "Vapor Phase Catalytic Esterification Rates" by R. A. Buckley and R. J. Altpeter, of the University of Wisconsin.

Regional Meeting Employment Service

With the recent increased demand for trained chemical engineers, those organizing the Minneapolis Regional Meeting arranged to hold an employment service clearing house. Their anticipations were well founded for representatives of 13 different organizations requested that they be allowed to interview prospective applicants. More than 54 interviews were held in the special interview rooms and quite a few other interviews were arranged under less formal circumstances.

SOUTH TEXAS

McKetta, University of Texas, Presiding.

Opportunities in Research and Development—*A. A. Draeger, Humble Oil & Refining Co., Baytown, Tex.*

Opportunities in Operation—*E. J. Fox, Carbide and Carbon Chemical Division, Texas City, Tex.*

Opportunities in Design—*George Mc-Granahan, Wyatt C. Hedrick Engineering Co., Houston.*

Opportunities in Economic Consideration in Process Design—*John E. Kasch, Pan American Refining Corp., Texas City.*

Opportunities in Technical Sales—*C. F. Reed, Dow Chemical Co., Houston. Reported by J. H. McLellan*

MARGINAL NOTES

For Direct Use by Profession

Data Book on Hydrocarbons. Application to Process Engineering. J. B. Maxwell. D. Van Nostrand Co., Inc., New York. (1950) 259 pp. $5.00.

Reviewed by Leo Friend, Associate Director, Chemical Engineering Division, The M. W. Kellogg Co., New York, N. Y.

THIS excellent book is a contribution from the Standard Oil Development Co., a research affiliate of the Standard Oil Co. (New Jersey), to the literature of process engineering as particularly used in the petroleum industry. To quote from the Preface, "The primary purpose of this book is to provide (1) basic data on hydrocarbons and petroleum fractions, (2) methods of applying these data to process engineering, including illustrative examples and some fundamental theory, and (3) applications of a few of the unit operations of chemical engineering used extensively in the petroleum industry."

The aim is accomplished by presenting correlations of physical, thermodynamic and chemical engineering data on hydrocarbons and petroleum fractions under the following headings:

A. Physical Data
 1. Physical Constants
 2. Characteristics of Petroleum Fractions
 3. Molecular Weight
 4. Vapor Pressure
 5. Fugacity
 6. Critical Properties
 7. Thermal Properties
 8. Density
 9. Viscosity
 10. Combustion

B. Unit Operations
 1. Flow of Fluids
 2. Flow of Heat
 3. Equilibrium Flash Vaporization
 4. Fractionating Towers

Each section is accompanied by a brief discussion of the basis and source of the charts and their application to specific process design problems. As such, this book represents a rather complete collection of information, arranged and presented specifically for the use of process engineers working in the fields of petroleum and hydrocarbon processing. The reliability and accuracy of this work have been tested by years of use by the technical personnel of the Standard Oil Development Co. and other affiliates of the Standard Oil Co. (New Jersey).

The information contained in this book may not be new to engineers daily engaged in process or refinery work. In general, these people have collected private data books or have access to company-sponsored data books containing equivalent material. For those engineers who are not fortunate enough to have such a data book, and require such data, this book will be of considerable value.

The graphs and charts in this book are different from those most commonly found in books and text in that they are designed for direct use. All the divisions customarily found in graph paper have been retained and the size is such that desired values can be read accurately without replotting, as is usually required. In addition, the book is printed in blue ink, which is easier on the eyes than conventional black for continual use. The reviewer feels that this departure is a good one and that authors of books containing charts which may be used by the reader for personal calculations might follow this example.

Mr. Maxwell's book is a fine contribution to the literature of petroleum processing.

With the Student in Mind

Natural Gas and Natural Gasoline. R. L. Huntington. McGraw-Hill Book Co., New York. (1950) 598 pp. $8.00.

Reviewed by M. F. Wirges, Gasoline-Chemical Division, Cities Service Oil, Bartlesville, Okla.

DR. HUNTINGTON states in his preface that "the preparation of this book has been prompted by the wish to meet the needs of engineering students taking courses dealing with the production of natural gas from crude-oil, condensate, and dry-gas fields, and the manufacture of liquefied products from this raw material." The author stressed the practical approach by using numerous illustrative examples and problem sections supplementing each chapter. This book should prove an invaluable aid to the undergraduate and to practicing engineers who are unfamiliar with the gas-gasoline industry.

Consisting of eleven chapters, this book includes such topics as estimation of reserves, elements of plant location and design, gathering and return systems, cycling efficiencies, absorption, distillation and fractionation, gas dehydration, storage and transportation, and high-pressure pipe-line research. The section on gas dehydration is excellent. It includes pertinent design data on the use of diethylene and triethylene glycols for gas dehydration, as well as information on dew-point testing and special equipment for dehydration plants. Chapters on absorption and on fractionation and distillation provide a good fundamental basis for complete understanding of these unit operations. There is also a comprehensive appendix.

The gasoline process engineer will be disappointed in that such sections as rich oil de-ethanization, later develop-

ments in oil-absorption process design, packed column design, and stripper design are covered briefly, and the book contains a large number of reprints of previously published articles. For example, the chapter on absorption includes a 20-page reprint on a study of froth heights and pressure differentials of bubble-plate columns. These data are too limited and specific for a book of this general nature.

To summarize briefly, this volume will give a good general idea of the natural-gas and natural-gasoline branches of the petroleum industry.

Living to Work

A Measure for Greatness—A Short Biography of Edward Weston. David O. Woodbury. McGraw-Hill Book Co., Inc., New York, N. Y. 230 pp. (1949) $4.00.

Reviewed by H. R. Glennon, Manuscript Editor, Chemical Engineering Progress.

THIS is another success story typically American except that the hero of this tale was an Englishman and did not become an American citizen until the end of his life when he was considered a citizen of the world. Edward Weston, electrical engineer, inventor of the dynamo, patentee, organizer of the Weston Electrical Instrument Co., and winner of the Perkin Medal for outstanding achievement in chemistry, arrived in New York in 1870 at the age of 20. His story as related by David Woodbury brings to life again the pioneering efforts in electric-arc lighting, electroplating, commercial photography, and electrical instruments.

Mr. Woodbury follows the course of Weston from his early days as an apprentice when he was building everything he could lay his hands on—models that worked in some way—to his years as organizer of companies promoting the business of electroplating and photography, subsequently giving the reader many glimpses of Weston as a fighter for his rights in the patent field which in those days, according to Mr. Woodbury, indulged in questionable practices.

However, it was the science of electrical measurement that interested Weston most. To explore the reasons for the lack of simple measuring instruments for testing dynamos, motors and lights became a consuming passion until after indefatigable labor and experimentation he had been granted four patents on electrical instruments.

A resident of Newark, N. J., Dr. Weston bequeathed to the Newark College of Engineering his library and his original models and drawings. He expressed the wish that a record be made of his researches, discoveries, and inventions. This volume is the result.

PEOPLE

W. E. LOBO, NEW CHAIRMAN, PROGRAM COMMITTEE, A.I.Ch.E.

W. E. LOBO   G. E. HOLBROOK

Walter E. Lobo of The M. W. Kellogg Co., has been appointed Chairman of the Program Committee by the Council of the American Institute of Chemical Engineers. He succeeds George E. Holbrook who has been Chairman since 1948. Dr. Holbrook, owing to increased responsibilities with the Du Pont Co., asked Council to appoint a successor. Mr. Lobo has been a member of the Program Committee since 1945 and he has also served on various other committees of the Institute such as the Publications (1946) and the Awards (1948).

VAN FLETCHER IN NEW JOB WITH DU PONT CO.

Appointment of Delbert Van Fletcher as assistant director of the technical division of the Grasselli chemicals department of the Du Pont Co. was announced recently. He had been process manager in the manufacturing division.

Mr. Fletcher is from Tampa, Fla., and a graduate in chemical engineering of the Georgia Institute of Technology, class of 1940. He received his Master's degree in chemical engineering from the University of Louisville in 1941, and then joined the Du Pont Co.

After working as a chemist at the Grasselli research laboratory in Cleveland, Ohio, Mr. Fletcher went into the manufacturing field, working at the Grasselli works in Linden, N. J., and Houston, Tex. He went to Wilmington as assistant process manager in 1948, and was only recently promoted to process manager.

F. E. MURPHY ADVANCED BY PENNSALT MFG.

Francis E. Murphy has been appointed production supervisor of the Wyandotte works of the Pennsylvania Salt Manufacturing Co. In this capacity, Mr. Murphy will be in active charge of all Pennsalt's chemical plant operations in Wyandotte.

Mr. Murphy joined Pennsalt in 1943 as assistant to the manager of research and development. In 1945 he was transferred to Pennsalt's Whitemarsh research laboratories as director of development, and in 1947 went into the manufacturing division as assistant production manager. Later he became supervisor of process controls, the position he held before being appointed to Wyandotte.

A graduate of St. Joseph's College, Philadelphia, Mr. Murphy is also a member of ACS and Franklin Institute of Philadelphia.

Gordon Kiddoo has been appointed director of research and development of the Continental Carbon Co., Amarillo, Tex. Mr. Kiddoo is a graduate of Cornell University with a degree in chemical engineering. He previously was with the Texas Co. in chemical engineering processing work, and in the design, construction and operation of pilot plants for the synthesis of fuels. He performed similar duties for Hydrocarbon Research, Inc., of Olean, N. Y.

J. N. Junkins is now associated as consulting chemical engineer with Johnson & Johnson, Engineers and Architects, of Chicago, Ill. He was formerly with the Vern E. Alden Co. of Chicago.

William B. Hudson, formerly located in New York with the Foster Wheeler Corp. as process design engineer in the petroleum refining division, has been transferred to Foster Wheeler Limited, London, England.

PIRET GOES ABROAD

E. L. PIRET

Edgar L. Piret, professor of chemical engineering at the University of Minnesota, and research consultant to the engineering department of the Minnesota Mining & Manufacturing Co., has received an appointment as a Fulbright research scholar for a year's work in France.

Dr. Piret sailed with his family Oct. 5 on the S. S. Liberte.

His was the only appointment in the field of chemical engineering for the next calendar year. Competition for the awards is national. Dr. Piret's program will include research in Paris and conferences at several universities and industrial laboratories on the European continent and in Great Britain. At Nancy, France, he will assist in the introduction of "American concepts of education in the field of chemical engineering."

The Fulbright awards, initiated by Senator Fulbright of Arkansas and sponsored by the U. S. State Department, are made to technical men, scholars and educators for advanced study and research in foreign countries.

HARVEY PROF. FOOD TECHNOLOGY ILL. INST.

Ellery H. Harvey, founder and past president of the Association of Research Directors and former director of research at Anheuser-Busch Inc., St. Louis, has been appointed professor of food technology at Illinois Institute of Technology, Chicago, Ill. He will also direct sponsored research and graduate studies in food engineering at Illinois Tech. The appointment is effective this fall.

Dr. Harvey served as research chemist for Swift & Co., 1926 to 1927; director of laboratories for Montgomery Ward & Co., 1927 to 1936; chief chemist at Wilson and Co., 1937 to 1941; and director of research at Anheuser-Busch Inc., 1942 to 1946.

Following World War II, he was awarded "the President's Certificate of Appreciation, for outstanding contribu-

PEOPLE

tions to the Office of Scientific Research and Development."

Dr. Harvey, who has received many degrees, is the author of numerous papers and holder of many U. S. patents.

PFORZHEIMER IN NEW JOB WITH S.O. (OHIO)

Harry Pforzheimer, head of the economics section of the Standard Oil Co. (Ohio), has been appointed to finance, research and analysis as staff assistant. Since his graduation from Purdue Uni-

H. PFORZHEIMER

versity in 1938 Mr. Pforzheimer has been associated with Standard, first assigned to technical service as a junior engineer. Subsequently he was named senior engineer and worked on the testing of equipment, and on design, installation and start-up of Standard's polymerization plants. In 1942 he was granted a leave of absence to accept an appointment in the Petroleum Administration for War in Washington, D. C. There he served in the technical section, refining division, and economics section, respectively. After his return to Standard at the end of 1945 he joined the refining control division and shortly thereafter when the economics section was established he was made its head. Currently he is a member of the executive committee of the Cleveland Section of A.I.Ch.E.

H. L. Barnebey has been appointed manager, and Sanford R. Bell process engineer, for the chlor-alkali department of Blaw-Knox Co.'s chemical plants division. This department of the company is active in the design and construction of chlorine-caustic plants based on the Mathieson mercury cell and processes employing amalgam to produce hydrogen peroxide.

CLASSIFIED SECTION

SITUATIONS OPEN

FLOW SHEET ENGINEER

Excellent opportunity in internationally known engineering firm in N. Y. C. for graduate chemical engineer with experience in flow diagrams, specification writing and instrumentation. Attractive salary with liberal pension plan and other employee benefits. Write, in strict confidence, details of education and experience to Box 1-10.

PROCESS ENGINEER

Permanent position on the process staff of an internationally known New York engineering firm for a top flight technical graduate with approximately five years' experience in petroleum or petrochemical field. Candidate should be capable of assuming responsibility for process design. Salary high and commensurate with experience. All replies in confidence. Box 2-10.

WANTED

Major Chemical Company in Western Pennsylvania, who is expanding present operations, has several openings for competent chemical engineers with three to ten years experience. Interested particularly in group leader grade or group leader potential. Work involved: process engineering studies, preliminary design, plant efficiency studies and pilot plant operation. Box 3-10.

SITUATIONS WANTED

A.I.Ch.E. Members

Process Development Engineer—Nine years' experience in process development, pilot plant, trouble-shooting, and production. Desire responsible position in process development and improvement and/or trouble-shooting. Fields include fats, oils, fatty acids, chlorinated products, and handling ethylene oxide and acetylene. Age 30, married, children, veteran. Box 5-10.

Chemical Engineer—B.S., M.S., Ch.E. Practice, M.I.T., 1943, top 5%. Age 27, married, veteran. Three years' experience development production. Four years sales purchasing. Highest references. Interested position New York-New Jersey area. Box 6-10.

Chemical Engineer—B.S. 1944, M.I.T. Age 28. Over six years' experience petroleum refining, including foreign service; manufacturing, design, and development problems. Desire position involving plant operations or liaison between plant and development/design. Box 7-10.

Management Engineer—Fifteen years' broad experience inorganic pigment manufacture in progressively more responsible management positions. Excellent record and broad experience in solution of process engineering and production problems. Accustomed to coordinating production, engineering, cost control and laboratory work. Considerable experience in preparation general economic reports and studies for higher management. Interested in production management position. Box 10-10.

Maintenance Engineer, Chemical Equipment—M.S. in Ch.E. Two years' extensive experience in specification and purchase of chemical equipment, design of specialized machinery. Direct shop activities in maintenance procedures and installations. Desire position with real future. Box 11-10.

Chemical Engineer—M.S., M.I.T.; Tau Beta Pi; age 26, family. Three years' successful, profitable experience in the study and design of new chemical processes. Desire research or development position with progressive organization in East. Box 12-10.

Chemical Engineer—B.S. 1948, 23, single. Production and development work on acrylic and thermosetting cast sheeting. Research and development work on phenolic resins and powders. Some pilot plant experience. Prefer development, production. Box 13-10.

Chemical Engineer—B.Ch.E., 1944. Age 28, married, veteran. Graduate courses, plus four years full time teaching; some research. Desire work in research and development. Excellent references. Prefer Philadelphia, Chester or Wilmington area. Box 14-10.

Chemical Engineer—B.S.Ch.E., N.Y.U., top 10%; M.S.Ch.E., M.I.T., 1950. Age 22, married. Undergraduate and graduate work in plant design. Prefer position in process development or production work leading to same. Location immaterial. Box 15-10.

Production Engineer—B.S. Chemistry, 1929. Seventeen years' experience with major company in plant production and operations, start-up, training, costs, safety, executive and administrative duties. Pharmaceuticals and organic chemicals. Box 16-10.

Nonmembers

SALES AND PRODUCTION ENGINEER

M.Ch.E. 1940 Columbia (A.B. '38), family. Ten years' varied experience engineering design, resin development, reinforced resin laminations, technical sales; administration and personnel work. Six years U. S. Marine Corps. Physically retired as Major. Desire technical sales or production; preferably plastic field. Prefer metropolitan area; vicinity, will travel. Box 8-10.

PEOPLE

(Continued from page 46)

L. ALLEN GOES TO SNELL

LYMAN ALLEN

Lyman Allen, formerly with American Viscose Corp., Philadelphia, Pa., as assistant chief design engineer, is now associated with Foster D. Snell, Inc. He is chief engineer of the engineering division in charge of chemical process design, including pilot plant operations, plant investigations, purchase, design and installation of equipment for clients.

Necrology

J. M. GRAHAM, JR.

James M. Graham, Jr., assistant director of Monsanto Chemical Co.'s general engineering department, died Sept. 23 from a heart attack. He was 43 years old. A native of Richmond, Va., he joined Monsanto at the Anniston (Ala.) plant in 1934 as an operating trainee and rose successively to become chief chemical engineer of the phosphate division. In 1945 he was transferred to St. Louis as a project engineer in the development department and in 1948 was made assistant director of the general engineering department. Mr. Graham was graduated from the University of Virginia in 1927 with a B.S. in chemical engineering and in 1929 received an M.S. in physical chemistry.

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In all cases the bundles consist of Brown Fintube hairpins rolled into the tube sheet in full compliance with the ASME codes. Metal bands, placed around alternate fintubes, prevent the longitudinal fins from interlocking and restricting the flow. This construction avoids baffling, and permits the liquids being heated to pass through the bundle *unobstructed*, in close contact with the fins and center tubes, with *low pressure drop*. Wide range of standard sizes.

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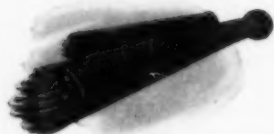
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